PROCEEDINGS

PART III. PETROLEUM

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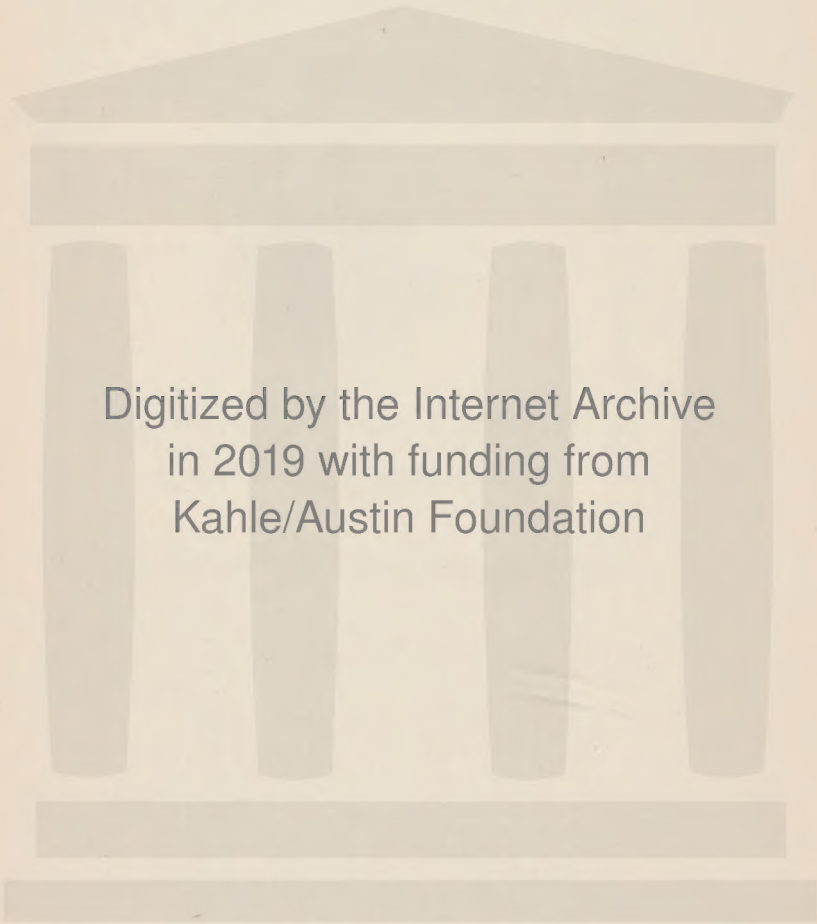
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Second (*Triennial*)

Empire Mining and Metallurgical Congress

PROCEEDINGS

PART III

PETROLEUM

(SECTION B OF CONGRESS)

PROCEEDINGS OF THE SECOND (TRIENNIAL) *EMPIRE MINING AND METALLURGICAL CONGRESS, CANADA, 1927.*

Part I.—Report of Proceedings, Inaugural and other Addresses, and General Papers.

Part II.—Mining.

Part III.—Petroleum.

Part IV.—Iron and Steel.

Part V.—Non-Ferrous Metallurgy.

The price of these Proceedings is $10.00 for the whole of the five parts, or any part may be obtained separately for $3.00.

Second (*Triennial*)

Empire Mining and Metallurgical Congress

Held in Canada, August 22nd to September 28th, 1927.

PROCEEDINGS

Edited by

R. P. D. GRAHAM

PART III

PETROLEUM

(SECTION B OF CONGRESS)

MONTREAL, CANADA:
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1928

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Second (*Triennial*)
Empire Mining and Metallurgical Congress

Canada, August 22nd to September 28th, 1927

Convening Body

THE CANADIAN INSTITUTE OF MINING AND METALLURGY.

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Second (*Triennial*)
Empire Mining and Metallurgical Congress

PREFACE

The conditions under which the Second Congress was held were different in several notable respects from those of the First Congress, which met in London in June, 1924. That meeting, convened by institutions and associations representing the mineral and metal industries, the colliery proprietors, and the iron and steel manufacturers, in the United Kingdom, lasted only four days, and the sessions were all held at the British Empire Exhibition, Wembley. It was, of necessity, inaugural in character, and apart from the presentation of a series of noteworthy papers dealing with various phases of the mining and metallurgical industries of the Empire, it had as its chief business the drafting and adoption of a Constitution and Rules for an Empire Council of Mining and Metallurgical Institutions. The Constitution as adopted is as follows:

CONSTITUTION

The Council shall consist, until otherwise determined, of two representatives from each of the following Constituent Institutions:

The Institution of Mining and Metallurgy
The Institution of Mining Engineers
The Institution of Petroleum Technologists
The Canadian Institute of Mining and Metallurgy
The Australasian Institute of Mining and Metallurgy
The Chemical, Metallurgical and Mining Society of South Africa
The South African Institution of Engineers
The Mining and Geological Institute of India
The Iron and Steel Institute
The Institute of Metals

OBJECTS OF THE COUNCIL

To serve as an organ of intercommunication and co-operation between the Constituent Bodies and for the promotion and protection of their common interests.

FUNCTIONS OF THE COUNCIL

(*a*) To foster and maintain throughout the Empire a high level of technical efficiency and professional status.

(*b*) To convene successive Mining and Metallurgical Congresses within the Empire.

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POWERS OF THE COUNCIL

The Council shall have power to initiate projects for consideration with a view to action and generally to direct the affairs committed to it by the Constituent Institutions, but it shall not commit them to any act or financial obligation without first obtaining the sanction of the respective Councils. Further, the Council shall not have any authority, implied or explicit, to interfere in the domestic affairs of any of the Constituent Institutions, whose complete autonomy shall remain intact.

Dr. R. C. Wallace, as President of the Canadian Institute of Mining and Metallurgy at that time, was one of the official delegates of the Canadian Institute attending the First Empire Congress in London, and on his return to Canada he submitted a proposal to the Institute Council that they should consider the feasibility of having the Second Congress meet in Canada. The proposal was received with enthusiasm, and a preliminary canvass of the situation having made it evident that the Institute might safely assume the responsibility of acting as convenor, an invitation was forwarded to the Empire Council to hold the Second Congress in Canada in 1927. This invitation was accepted by the Empire Council on behalf of the Constituent Institutions.

The Second Congress opened in Montreal on August 22nd, with addresses by the Honorary President, The Right Hon. Sir Robert S. Horne, *G.B.E.*, *K.C.*, *M.P.*, and the President, the Hon. Charles Stewart, *M.P.*, Minister of Mines for Canada. Technical sessions were held on this and the following day, the proceedings including the presentation of a notable paper by Sir Thomas H. Holland on a *Proposed Review of the Mineral Resources of the Empire.* The proposals outlined in this paper were warmly endorsed in addresses by official representatives from various parts of the Empire, and at the conclusion of the discussion the following resolution was adopted:

This Second (Triennial) Empire Mining and Metallurgical Congress, assembled in Canada, having discussed a proposal for instituting a review of the mineral resources and industries in each appropriate administrative unit throughout the Empire, and of the conditions affecting their development, embodied in a paper submitted under the auspices of The Institution of Mining and Metallurgy by Sir Thomas H. Holland,

RESOLVED, that the proposal be referred to the Empire Council of Mining and Metallurgical Institutions, to be transmitted to the Councils of the constituent bodies for consideration, with a request that they will formulate their views and communicate them to the Empire Council for further action.

On the following day, special trains conveyed the party to Ottawa, where members had the opportunity of meeting His Excellency the Viscount Willingdon, Governor General of Canada, and The Hon. Charles Stewart, representing the Prime Minister, at a luncheon tendered by the Congress.

Following this, two days were devoted to technical sessions in Toronto, and over the week-end there were excursions to Hamilton, Niagara Falls, and other points of interest.

From Toronto, the Congress trains proceeded to some of Ontario's world-famous mining districts, visits being paid in turn to nickel-copper mines at Sudbury, silver mines at Cobalt, and gold mines at Kirkland Lake and Porcupine.

After leaving the Porcupine area, the party divided, those who had elected to take Tour *A* going westward to the Pacific coast, while Tour *B* proceeded eastward across Quebec and the Maritime Provinces to Newfoundland. In each case the principal mining centres and metallurgical plants, as well as some hydro-electric plants, were visited, and a number of technical sessions were held: on Tour *A*, in Winnipeg, Vancouver, Jasper, and Quebec; and on Tour *B* in Quebec and St. John's, Newfoundland. Tour *A* covered approximately 7,750 miles, and Tour *B* 5,525 miles. The final session of the Congress was held in Quebec on September 26th. It is with considerable gratification that we are able to record that, from the opening day to the closing of the Congress, there was not a single case of illness nor an accident of any kind.

Official banquets were held in Montreal, Toronto, Winnipeg, Vancouver, and Jasper, and in St. John's, Newfoundland. At numerous other points the Congress parties were lavishly entertained by mining companies and individuals; and golf and other clubs in the various cities visited were most hospitable in extending facilities for recreation. The Congress is especially indebted to the Ladies' Committees, which, at each stopping place in the course of the tours, were indefatiguable in providing entertainment for the visiting ladies.

Lists compiled from the official registers and other available sources show that the total attendance at the Congress was well over twelve hundred. Of these, 350 participated in

Tour *A* and 96 in Tour *B*. The gathering may be truly described as exceptionally well representative of every important phase of the mining and metallurgical industries in all parts of the Empire. The personnel included official delegates from each of the following institutions:

The Institute of Metals (London)
The Institution of Mining Engineers (London)
The Institution of Mining and Metallurgy (London)
The Iron and Steel Institute (London)
The Institution of Petroleum Technologists (London)
The Chemical, Metallurgical, and Mining Society of South Africa
The South African Institution of Engineers
The Rhodesia Chamber of Mines
The Australasian Institute of Mining and Metallurgy
The Mining and Geological Institute of India
The Canadian Institute of Mining and Metallurgy

In addition, the Congress had the privilege of welcoming official delegates from the United States Bureau of Mines and the American Institute of Mining and Metallurgical Engineers.

A total of 42 papers were presented at the several technical sessions, and with the exception of three these were all printed as 'separates' in advance of the opening of the Congress and distributed to delegates before the meetings. In addition, a 270-page Official Programme was issued giving complete information regarding arrangements for the Congress, with itineraries of the excursions and brief descriptions of the various points of interest visited; and a series of 'short focus' papers was prepared, each giving in concise form particulars of operations at individual mines and metallurgical plants inspected during the tours. Besides these purely Congress publications, specially prepared booklets descriptive of the Dominion's mining and metallurgical industries were issued by the Federal Department of Mines, by the Ontario and Quebec departments of mines, and by several of the mining companies.

The papers submitted to the Congress dealt with a wide variety of topics relating to recent progress, and the present status and future prospects, of the mining and metallurgical industries in almost every section of the Empire where these industries are carried on. Many of the papers have been given wider publicity than was possible at the time of the

Congress by publication in the *Transactions* of the constituent institutions, and some also in technical journals. Following the procedure of the First Congress, the complete *Proceedings* are now issued in five Volumes, a full list of the Papers being printed in each volume.

The funds required for carrying out the extensive programme of the Congress were in the main contributed by the Dominion Government, by the governments of the several Provinces, by the Government of Newfoundland, by Canadian mining and smelting companies, and manufacturers of mining machinery, explosives, etc., and by the Canadian Pacific and the Canadian National railways. Generous donations were also received from co-operating Institutions in the United Kingdom, South Africa, Australasia, and India. In all, sixty-six contributions were received, totalling about $110,000.

The Second Congress was exceedingly fortunate in having, as its Honorary President, the Right Hon. Sir Robert S. Horne, *G.B.E.*, *K.C.*, *M.P.*, who took a most active interest in the proceedings and participated in the Montreal meeting. Much of the success of the Congress was due also to the President, The Hon. Charles Stewart, Minister of Mines for Canada, who rendered great services, both personally and through the Department of Mines, technical officers of which were detailed to accompany each of the special trains, and were available at all times to give information regarding the Dominion's mineral resources and industries. The Congress also received whole-hearted support from the departments of mines of each of the Provinces of Canada, and from the Government of Newfoundland.

Mining companies throughout Canada, and also the two great transcontinental railway systems, the Canadian Pacific and the Canadian National, and the Temiskaming and Northern Ontario railway, took a very active interest in the work of the organization and showed a keen appreciation of its importance to the Empire. The Congress owes much to them for their invaluable co-operation, and also to the management of the various mines and plants visited for their unfailing readiness to do all in their power to make the tours both instructive and enjoyable.

Acknowledgment must also be made of the notable service rendered by the numerous individuals who composed the various committees responsible for the organization and carrying out of the Congress. The smoothness with which the entire Congress programme functioned is a splendid tribute to the efficient manner in which each of these committees carried out the particular duties assigned to it.

We desire further to record our thanks to the Empire Council of Mining and Metallurgical Institutions, and more especially to its joint general secretaries, Mr. Charles McDermid and Mr. George C. Lloyd, for much helpful advice both during the organization period and while the Congress was in progress. Thanks are also due to the Cunard Steamship Company for the excellent arrangements they made for the comfort of delegates who sailed from England to Canada in the official Congress boat, the *Alaunia*.

Although the Empire Council Banquet, held in London on November 22nd, was an aftermath, and not a part of the actual proceedings, of the Congress, it may be fittingly referred to here since a large proportion of those present had been with the Congress in Canada, and one of its objects was to review the results of the Congress. Notable speeches were delivered by Sir Thomas H. Holland, Chairman of the Empire Council, who presided, and by others prominently identified with the mining and metallurgical industries, as well as by representatives of the governments of various parts of the Empire.

GEO. C. MACKENZIE,
General Secretary.

R. O. WHEATLEY,
Associate Secretary.

923 DRUMMOND BUILDING,
MONTREAL,
April, 1928.

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PART III—PETROLEUM

(Section B of Congress)

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CONDITIONS AFFECTING THE PETROLEUM PROSPECTS OF THE EMPIRE

By Sir Thomas H. Holland (*Member, Inst. Petr. Tech.*)

(Jasper, Alta, Meeting, September 19th, 1927)

As the result of the War, the Governments of civilized Powers have learnt a few lessons regarding the special importance of minerals among the raw materials that are essential to industries; their annual outputs also have since generally exceeded the records of the years preceding 1914. In the year just past, the mineral production of the world amounted to nearly 2,000 million tons, and of this total the British Empire produced about one-quarter, whilst the United States produced two-fifths. Thus, between them, the two great English-speaking powers control just two-thirds of the world's supply of minerals.

Of all the international puzzles which the League of Nations and their friendly associates have been attempting to solve since the War, mineral questions present certain features that are peculiar, and thus deserve special consideration in framing any economic policy or in devising measures to ensure military security:

(1) Unlike the distribution of animal and plant products, which can be modified within certain limits by artificial means, mineral deposits are fixed irrevocably by Nature, irrespective of climate and political boundaries. Thus, some international movement of mineral products is inevitable, and this fact should be considered as basic in devising fiscal measures.

(2) Mineral deposits are wasting assets; they are essential for the maintenance of civilization such as we know it now, but they can be used once and once only in the history of each country that possesses them.

(3) For the maintenance of normal civilized activities, the British Empire and the United States must exchange a few mineral products, whilst the other nations are much more definitely dependent on these two for their essential requirements.

(4) The British Empire contains a wider variety of minerals than any other national unit; and, whilst it has an exportable surplus of some that are essential, like cobalt, nickel, mica, and tin, its requirements of others exceed its own production; of this latter class *petroleum* is about the most important and the one that immediately concerns this special discussion.

A purely technological institution does not dabble in politics, but we cannot help being conscious of the fact that our activities bring us into contact with many of the international problems that are affected by oil. Export and import tariffs are now imposed, modified, or abolished for reasons that have little or no visible connection with the economic aspects of minerals; often these questions are used by one political party merely as instruments to lever an opposed party out of office, without regard to whether the Empire or any part of it has or has not enough of those mineral products that are essential to its industrial development.

In the same way, the State ownership of minerals has been lumped with the very different question of the State ownership of mines, in order to create a political party cry of sufficient amplitude for electioneering purposes.

The changes in the general configuration of the international equilibrium which have occurred since the War have now produced an additional set of problems, which, though economic in foundation, are in danger of becoming obscured by an excessive national consciousness. We now find such formulæ as "equal opportunity and the open door" coming into conflict with another phrase of American manufacture—"self-determination." As a consequence of taking this last phrase seriously, the smaller nations naturally think of safeguarding for the use of their own nationals their resources in raw materials; and this unexpected development some of our American friends complain of as being contrary to the general interests of civilization. But this point will be

considered more fully in a later paragraph of this paper. The danger of being governed by phrases and slogans in international as well as in domestic politics can be reduced effectively only by a cold analysis of the essential facts—facts regarding the natural distribution of minerals, and facts regarding the way in which their uses in fundamental industries are being affected, or, what is even more important, are likely to be affected, by impending technical developments.

Technologists can help by collating the facts and summarizing them in a form that will permit of simple economic deductions; and there is a danger that, without an occasional independent, non-political stock-taking of this sort, our continual compilation of unrelated data concerning highly specialized parts of the group of subjects that constitute petroleum technology, will leave our work sterile and without purpose or direction: we shall always be in the condition of being unable to "see the wood for the trees," unless we get outside occasionally and correct our perspective.

The Empire Congress of Mining and Metallurgy, assembled in Canada, gives us an opportunity to discuss with our "opposite numbers" in the Dominions the question whether we can with advantage now undertake an estimate of the conditions that affect the development of petroleum; if so, in what direction and to what extent can we explore those questions that are fundamental to the economic progress of each self-contained unit of the Empire, and therefore of the Empire as a whole?

The Institution of Mining and Metallurgy, one of the other constituents of the Congress, intends to explore similar questions for the non-ferrous minerals, which include some problems that are different in nature from those that have grown up around oil. Among the non-ferrous minerals there are some products, which, commercially, in times of peace are relatively unimportant, but which in time of national emergency may suddenly become of vital importance.

Petroleum, however, is one of the major mineral products in the commercial sense as well as one of supreme importance in the present state of technical science for measures of defence. The exploitation of petroleum has become controlled by companies sufficiently powerful to establish their own intelligence

branches and sufficiently influential to advise their Governments on questions of international policy; for their interests and the interests of the nation as a whole roughly coincide. We can therefore with some confidence restrict our own discussions to those technical aspects of oil which are likely to affect the trend of industrial and commercial developments.

The questions that suggest themselves as suitable for discussion include these:

(1) Having in view the present state of our geological knowledge of the various parts of the Empire, what are the prospects of maintaining or of extending our present production of crude prtroleum ?

(2) To what extent is it likely that these supplies can be supplemented by the exploitation of oil-shales ?

(3) What are the prospects of obtaining oil from the low-temperature treatment of appropriate sections of the coal family ?

(4) Whether there is a prospect in the early future of obtaining oil-substitutes by processes like the hydrogenation of coal.

(5) The prospects of supplementing oil supplies by other forms of liquid fuel, such as alcohol.

(6) The prospective development of those processes that are necessary for obtaining from crude oil larger fractions of those lighter hydrocarbons that are required to meet the demand caused by the multiplication of internal combustion engines.

Many subsidiary questions arise from these six general propositions; some are within our special province, as for instance the supplies of accessory mineral products and chemicals that are necessary for new developments in refining processes; even the measures being taken within the Empire to train the required technical specialists must not be overlooked. Other questions that affect fuel prospects generally lie outside our special sphere of influence, as, for example, the development of hydro-electric power, which affects coal as much as oil as an essential source of motive power.

It should be understood that not one of the questions just indicated is capable of being answered in precise terms; and it is for this very reason that a new discussion is suggested.

For a Government to frame a policy that is most likely to meet the prospective needs of a country it must necessarily rely on the judgment of those specialized technologists who are able to estimate with accuracy, although not necessarily with precision, what is likely to occur in the near future. Obviously, no Government can rely on statistics alone; they, for instance, can never give the slightest idea whether new oilfields are likely to be discovered; whether, if crude petroleum supplies fail, we can hope, with reasonable hope, that other sources of liquid hydrocarbons will take the place of natural oil; or whether, and in what directions, we ought to shape our policy to meet the changed circumstances that may arise in the near future.

The papers that follow record the dominant impressions of specialists in four groups of these problems. They are purposely thumbnail sketches of the general situation, not detailed surveys, and they have been prepared mainly to test the proposition that the time is now ripe for forming standing Committees in each Dominion in order to estimate the ways in which recent developments in petroleum technology, that have a bearing on commercial activity, affect Empire problems of economic policy and of military security.

There is one matter which we have not attempted to include in this series of studies, although it must have an important influence on the development of petroleum, as it has on all minerals; that is, the statutory conditions laid down in each Dominion and Colony for granting rights to explore, to prospect and to drill for oil. Such regulations have been actively tested in India, with Burma, in Canada, and in some Colonies.

The only area with which I have personal acquaintance is India, where the old rules have been altered in recent years to meet the circumstance that oil is unlike other minerals because of the absence of a sharp class distinction between prospecting and exploitation. Prospecting is possible only by drilling and generally by deep drilling, often in remote areas that are not readily accessible for heavy plant. The ordinary maximum limit of three years laid down as applicable to prospecting licences for other minerals is thus unsuitable for oil.

With a new field also in regions where there is no established refinery, it is obviously necessary that a pioneer company should have rights over more than the usual area in order to justify the capital expenditure necessary on pipe-lines and refining plant. The permissible features of the standing regulations are in general satisfactory, but their application by local officials too often suggests a failure to recognise the fact that prospecting is not an end in itself; no wise company would prospect without certainty of obtaining land enough to meet requirements of a refinery on a scale sufficiently large to handle on commercial lines the smaller of the marketable products.

Recently, the Government of India have issued a circular letter with the object of collecting opinions on a proposal made for disposing of mining concessions on a system of auction or by competitive tenders. No system could better suit the type of parasite that seems to spring up by spontaneous generation in every oilfield; and the fact that it is discussed seriously shows how far some of our Governments have had their centres of gravity disturbed by the atmosphere of war.

No incident could have demonstrated more effectually the necessity of forming independent, non-official bodies to criticise measures of economic policy that affect, or fail to affect, the development of the mineral industries.

An essential base-line for all questions of development can be constructed only by a review of the figures for the production, the movement and the consumption of each mineral. For the production and movement of minerals, the Mineral Resources Branch of the Imperial Institute collects the principal statistics. They do not always distinguish between varieties of the same mineral species, and from the point of view of technical industries, mineral varieties differ as much as mineral species from one another.

Nor do statistics of the sort give the slightest hint of impending technical developments which affect the use, and therefore the prospective value, of mineral deposits. No official, or even officially-supported, body can publish its views regarding the probable trend of any mineral industry.

It is too heavily weighted with the sense of responsibility; and its pronouncements, therefore, must necessarily lag behind the times, just as a dictionary lags behind the current vernacular of every language.

The full published statistics of a body like the Imperial Institute can at latest cover the year before last. But it is obvious that the questions which we have in view are not of the kind that can be solved by means of Government statistics. The figures now collected for the production of crude oil and for the movement of products are of value as a guide to the future only because of the circumstance that no field dries up suddenly; nor is it probable that new unforeseen supplies will arise suddenly in the Empire.

There is no country in the world better provided with statistics than the United States. yet the two leading bodies connected with mineral technology were not satisfied, and considered it necessary in 1920 to set up a Joint Committee to review the effects of the mineral policy of America and the lessons learnt by the War. This Committee, under the chairmanship of Prof. C. K. Leith, appointed Sub-Committees for the intensive study of each important mineral, one being devoted to *Petroleum*. The Sub-Committee for petroleum reported in 1923, and again in 1925, and its conclusions are worth studying. I will refer to a few that seem to be specially important(1).

It is assumed that the sedimentary rocks of the United States should be regarded merely as samples of those which cover a large part of the continental surface of the world. It is concluded therefore that, "as the ultimate production of the United States is to the area of the sedimentary rocks of the United States, so the total oil production of the world is to the whole area of sedimentary rocks of the world."

The Sub-Committee does not regard the enormous production of oil in America to be the mere result of its special endowment by Nature, but they point to American temperament, American initiative, and the demands of their phenomenal industrial and social developments, as important factors.

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(1) "International Control of Minerals," New York, 1925, pp. 87-103.

It follows from this line of reasoning that the natural supplies of petroleum in the United States are more nearly exhausted than in other countries. It is pointed out that Russia probably contains as much as, and probably more oil than, the United States, but its development has been delayed by unintelligent legislation.

The Sub-Committee is of opinion that preferential duties, tariffs, embargoes, and bonuses must always in the long run react to the detriment of the nation which uses such fiscal medicines of temporary and local value. They are thus out for free trade in petroleum.

In discussing the question of local refining in the country of production, the Sub-Committee points out the wisdom of encouraging local operations, but these conclusions are hedged with some qualifications.

The Sub-Committee supports the General Committee in urging that national aspirations should not be permitted to interfere with attempts by extra-nationals to exploit any country's oil deposits, as it is no disadvantage to any State for foreign capital to be employed in it during peace-time, whilst, in times of war, there is an advantage in having a mineral field ready developed.

It is evident that the Sub-Committee is looking to the time when the consumption in the United States will permanently outstrip home production, and oil companies will want more definitely than hitherto to secure exploitation rights in other countries. Having this circumstance in view, the Sub-Committee urges the American Government to give its protection and support to an American company that wishes to enter a foreign field; it even goes so far as to recommend that the Government should discriminate between the claims of rival American companies and then back what they select to be the right one.

This international aspect of mineral questions seems to have grown in importance recently among American technologists; for the recommendations of Prof. Leith's Committee and associated Sub-Committees state in relatively sober

language, and mainly by inference, a group of sentiments more openly expressed in a book of special articles published in 1920 under the editorship of Mr. J. E. Spurr, a distinguished mining geologist, whose views are always taken seriously.

The following extracts will show the way in which the readers' thoughts are there directed:

"Many nations, like England, France, Holland, Argentina, and Mexico, have taken steps looking toward a partial nationalization of their petroleum resources, in order to protect themselves against foreign commercial aggression in this particular. England has gone farthest in this direction, and has reached and is reaching out aggressively into other countries to secure, through commercial control, backed where necessary by political pressure, a world empire of petroleum to serve her world-wide colonial empire. The United States, on the other hand, has dominated the world's petroleum industry through her own vast resources, worked by interests which have grown without conscious governmental help or even in spite of governmental and popular opposition, and have reached out and secured footholds in other countries" (p. 2).

In a final chapter, significantly headed "Who owns the Earth?" Mr. Spurr reviews the lessons indicated by the special studies of the separate minerals, with a view of estimating their commercial and political control. He contrasts the British and American policies as follows:

"The imperial policy of expansion and increasing political control has become a tradition and an instinct with Great Britain; she learned since the loss of her American colonies to give full autonomy to her more intelligent colonies, so that she strengthens her dominion thereby, and persistently goes on her way putting more and more of the earth under the British flag. The wealth and resources of the United States being so far greater than its necessities, foreign problems have resolved into occasional questions of self-protection; and from this condition a directly resulting theory has sprung of non-interference in the rest of the world."

It is well "to see oursels as ithers see us"; but one would feel much more comfortable as a Britisher if one could be certain that what appears to Americans to be successes in our foreign policy were the results of deliberate activity by our statesmen. More often the successful expansion of British commercial influence occurs in spite of the efforts of our political party leaders.

Conditions in America have not so far been affected by those centrifugal forces which have for long impelled, and still impel, the Britisher to push out into the unknown. The prospecting spirit which characterises the individual,

dominates also the British commercial firm. The American has hitherto had enough elbow-room in his own country, which has the double advantage of possessing minerals in great variety and sufficient quantity, distributed over a wide area within which internal free trade is completely unhampered by fiscal hedges.

Americans would be wise to remain happy with their natural good fortune; but Mr. Spurr and his collaborators seem to think that the apathy of the United States Government, contrasted with the active policy of some European powers, is developing into a national danger. Mr. J. D. Northrop, the author of the article on Petroleum, remarks(1) that:

"Unless the United States adopt measures, such as Federal operation of the trunk pipe-lines, to limit the aggressions of foreign capital in this country, and erects a firm forward-looking governmental policy toward the protection of investments of its citizens in petroleum properties in other countries, particularly Latin-American countries, it may witness its commercial supremacy in petroleum affairs wane and disappear, while it is yet the largest political contributor to the world's supply of petroleum.

"As contrasted with the strongly nationalistic and deliberately aggressive governmental policy adopted by Great Britain, France, Holland and some other nations, the United States has never adopted any policy founded on recognition of the importance of political and commercial control of petroleum."

In reciting the mineral laws, which exclude foreigners from mining rights in British territory, Mr. Northrop accepts some well-distributed errors of fact. He states that:

"In Burma a monopoly of the petroleum industry for 99 years was granted to the Burma Oil Company in 1865. This grant seems to have been inspired by fear of the Standard Oil Company of the United States, for the agreement between the company and the Government stipulates that the former shall not amalgamate with other oil companies."

The Burmah Oil Company was not in existence in 1865, and Upper Burma was not annexed till 20 years later; its annexation was not influenced by prospects of oil, which were then of no apparent importance. The Burmah Oil Company has not and never had any form of monopoly in Burma, and indeed whenever the local Government of Burma has displayed any independent initiative, it has been in the direction of hampering the enterprise of these pioneers who first discovered and developed the oil resources of Upper Burma.

(1) *Political and Commercial Geology*, 1920, p. 18.

Mr. Northrop need not have undertaken an excursion to foreign lands to find Government action "inspired by fear of the Standard Oil Company." Whatever may have been the reasons for the action of the Government of India in showing a want of hospitality to a large foreign oil company, I cannot now discuss without danger of drawing on my memory of past official days; nor is it necessary to do so; for the advantages to the Standard Oil Company itself of the decision—whether through accident or political wisdom—has been shown by the blank results of subsequent prospecting operations in every possible oil-bearing part of the province outside the fields which were already occupied by other established oil companies when the Standard Oil Company showed an inclination to take up land in Burma.

Anyone who knows the history of petroleum prospecting in Persia will remember that it was the personal enterprise of Mr. W. K. D'Arcy and his subsequent personal determination to keep his company, at any cost to himself, in British hands that made it possible for the Government afterwards to accept an investment that proved to be of national importance in the war.

The investment of British capital in Persia and in so many other foreign oilfields of the world is in no way due to Government help, nor is it the product of Government policy; but it is the direct outcome of the very spirit that laid the foundation of American economic prosperity in the British colonies from which the United States have developed.

However, these are by-products that fall outside the immediate purpose of this paper, which is to introduce a discussion, not to settle its merits. My object is to point out the nature of some of the problems that might be worth consideration at the Congress; and the papers to be presented after this introduction give you four sketches from which you will be able to advise the Council whether the time is now suitable for proposing for any of the Dominions or Colonies unofficial Committees, commissioned to review the petroleum situation, as has been done with commendably patriotic fervour for the United States.

The papers in any event will be available for discussion at the Congress, even if we decide or they agree that no further organised action is necessary at this stage; for all the papers which follow estimate the trend of development in special branches of petroleum technology.

Sir Frederick Black takes a long view of the situation, and his cheerful estimate for the next decade or so helps one to accept Prof. Nash's impression that the various schemes for obtaining oil substitutes from coal and other such raw materials have still many technical difficulties to get over, before we shall see liquid fuels on the market at prices to compete with the existing products of free petroleum.

With an assurance of sufficient total supplies of crude oil for another decade and probably another generation at least, the problem of most immediate interest to the Dominions is that raised by Sir Frederick Black regarding the necessary movement of oil products. The streams of crude and refined products now cross one another on the ocean, and it is for each Dominion to estimate the possibility of any one of the streams being interrupted by war conditions or being diverted by new tariff conditions.

Mr. McConnell Sanders reviews the refining capacity of the Empire as distinct from its capacity to produce crude oil. He shows that the total refining capacity is about sufficient to handle 7—8 million tons of crude, divided as follows:—United Kingdom and Canada $2\frac{1}{3}$ million tons each, India $1\frac{3}{4}$ million tons, Sarawak and Trinidad about $\frac{1}{2}$ million tons each.

The total consumption of petroleum products in the British Empire, however, amounts to about 10—11 million tons, whilst its own output of crude oil is only about 3 million tons. Thus, the Empire is dependent on outside sources, not only for three-quarters of its normal requirements of petroleum products, but it has still insufficient refining capacity, even if it could be sure of getting a sufficient supply of crude.

It is obvious that any estimate of this sort, limited to total capacity, is in itself insufficient, as it takes no account of the circumstance that we should still want of certain products more than we should get by refining the total of 10—11 million tons of crude oil. Nor does it take into account the fact that our principal demand is in Great Britain, where the only visible sources of raw material are oil-shale and some fractions of the coal family, neither of which for some years to come will be able to compete with crude oil.

There are three comments that seem to be allowable on this broad statement of the position as it is now:

(1) Under normal conditions we must depend on outside sources for a seriously large part of our petroleum products; for there seems little hope in the near future of turning our oil-shale and torbanite to account in quantity sufficient and with commercial profit to meet the growing demand for the various products of oil;

(2) The recent establishment of a large refinery in South Wales is a definite if still, qualitatively as well as quantitatively, insufficient contribution towards home stability; for obviously, if ocean communications were interrupted in any area, it is more likely that crude oil will still be obtained from another area than that any special product of the refinery will so be secured at will.

(3) It is important to remember that in case of temporary isolation, even the Empire sources of crude oil may not be accessible. In any event, they would be quite insufficient even if they were available to the full, and thus the prospect of obtaining oil from materials other than crude free petroleum is one that is of special importance to Britain. Of the problems of this class the utilisation of oil-shale is the most important, for this country and three of the great Dominions happen to have stocks in abundance.

As regards two of these Dominions, Australia and South Africa, the oil problem is limited by reason of the fact that neither can count on a source of crude petroleum, whilst in Canada the question of developing the Alberta tar-sands will supplement the supplies of raw materials of other sorts.

These points are referred to merely to indicate the desirability of leaving each Dominion to work out for itself the estimate of its own prospects and needs; and thus, although the call for special non-official 'watch' committees for oil may not be as obviously necessary as for some other minerals, the case for local action is the same. No committee in England and no official organization of any sort, here or anywhere else, can tackle the problems that we have in view; the necessary mobility can be obtained only by freedom from responsibility for Government policy. But one result of the activity of non-official committees will be a reduced temptation to somnolence by official organisations, and such local committees will have proved their value if, in this way, they are found in the near future to be no longer necessary.

ECONOMICS OF THE PETROLEUM SITUATION IN BRITISH DOMINIONS

By Sir Frederick Black (*Past President, Inst. Petr. Tech.*)

(Jasper, Alta., Meeting, September 19th, 1927)

An outline survey of the economics of petroleum in British Dominions resolves itself broadly into the consideration of how oil supply and demand are balanced at the present time, and whether, and how, and under what modifications, if any, that balance is likely to be maintained in the near future. Happily, however, this kind of survey does not necessarily involve the presentation of a complete balance sheet of prophecies and anticipations. The most we can expect to do is to draw out, from available data, some few reasonable inferences as to the probable course of events in the field we are setting out to examine. For the rest we must depend for necessary action upon a continuity of vigilant watching and periodical reviewing of actual happenings and tendencies. Before we can set to work to examine the oil position of British Dominions we must look at some of the underlying principles of an economic review of oil. We must also glance over the petroleum field generally and see what activities are afoot. Above all we must realize that the natural petroleum question is only a part, perhaps the most important for the moment, of a general fuel problem. Fortunately in the course of our survey, as we shall show later on, we shall meet with evidence of remarkable and encouraging activities and of attention to this problem in many branches of industry and invention, more or less directly associated with the production and utilization of petroleum.

Economic surveys of the petroleum situation, sometimes from a world-wide standpoint and sometimes from that of a particular country or group of countries, have been made at fairly frequent intervals ever since the oil industry started

upon its modern phase some sixty or seventy years ago. Such surveys have sometimes led to pessimism and almost to panic, and at other times to an equally unreasoning optimism and almost somnolent complacency. The happy mean is a sane optimism, tempered by eternal vigilance and activity. This point may be put with high authority in words recently used by Sir John Cadman (chairman of the Anglo-Persian Oil Company), "The history of the oil industry since its inception has been a story of steady progress, continually belying the constant stream of unfavourable prophecy." For the most part it has been the probability or otherwise of the maintenance or increase of oil production that has received the largest measure of attention. Increasingly, as would be expected from the growing influence of the geologist in petroleum exploitation, estimates of the areas that might prove oil-bearing have been made by geologists. Data thus furnished clearly rest on a more scientific, if less optimistic, basis than those of the practical but non-scientific persons, who would have undertaken, not without cheerfulness, the functions of prognostication in the earlier periods of the development of the industry. Nevertheless even geological estimates have necessarily considerable limitations and are open to modification by other experts and sometimes to more than one interpretation. Geologists have not in all cases actually gone over the whole of the territories which they may include in the region of possible future oil fields. It is true, as recently remarked by the Editor of an English Oil Journal (*Oil News*), the world has now been to a very great extent 'criss-crossed' by the exploratory journeyings of geologists. When their estimates become available they are not infrequently subjected to modification by persons of experience in the oil industry, *e.g.*, as to whether the areas are or should be limited to those where actual surface indications, seepages, etc., exist, or whether they do or should include all lands the underlying structures of which may be promising from an oil standpoint according to past experience, irrespective of surface indications. When, on considerations of this nature, the critic has decided whether the promising areas to which the geologist points need to be increased or decreased and in what ratios, there comes up this further question, viz., what average unit of supply per acre shall be taken for

each typical area to reduce to barrels or tons the potential oil supplies of the total areas in question. Here again there is room for a choice of alternatives according to varying experience in many different fields. In times, as is often the case, when over-production is the predominating feature of the oil industry and new markets and uses, not necessarily the most efficient and economical, are being eagerly and hastily sought for flush production, price, at all times important, seems to be then the one great and governing factor. A low price for the product will probably be adopted to attract the new customers and a reduced figure will be offered or 'posted' for crude to check new exploitation not immediately necessary. In the opposite state of things, viz., a shortage of production as compared with demand, a raising of prices of products and crude should check consumption of products on the one hand and normally, on the other hand, bring in additional supplies of crude to the pipe lines. But price is not always an all-powerful factor. Conceivably there might come a shortage which no reasonable raising of prices would make good and in such a case oil in the desired quantity might not be, as Carlyle said of sleep, "in the market at any quotation." This we need hardly say is an extreme contingency, but it is essential that we should not exalt the price factor beyond what it can really accomplish.

Fluctuations of price and supply may be steadied to a limited extent by storage of additional reserves. This is essential up to a point to keep refineries going and temporarily to meet the markets' demands, but it is an expensive procedure and cannot be carried beyond a certain reasonable point which commercial experience and finance will tend to fix. In the classic instance, "the leading reserve-storage case" of history, so to speak, the great Egyptian administrator, Joseph, had practically only the one remedy to fall back upon, viz., the building of barns and the piling up of reserve stocks of grain, when, in the seven fat and prosperous years, he made provision against the seven lean years that foresight and special inspiration led him to expect. Here let us interject parenthetically that oil reserve stocks of today above ground provide more nearly for seven months' demand than that of seven years. Joseph in Egypt took measures which probably astonished and perhaps moved to scorn the complacent people who were

satisfied with the existing plenteous harvests, but were ready enough to benefit by their ruler's foresight when the lean times came. We need not unduly labour this ancient and well-worn instance of the practical application of the laws of the so-called 'dismal science' of economics, long before that science had received a name or became the subject of treatises, The 'corn in Egypt' illustration does however help to suggest one or two further thoughts which may be not unworthy of a few moments' attention. Joseph was dealing with something, viz., wheat, which was practically wholly a necessity of life, and not in certain cases a necessity and in others a luxury, as is the case, let us say with motor spirit, used almost as a necessity for industrial purposes, and also as a luxury, though sometimes a very reasonable one when ample supplies are available, for what is known as 'joy-riding,' which may be 'health riding,' in automobiles. In ordinary circumstances Government and peoples in most countries have very strong and reasonable objections to 'sumptuary laws.' In war, or other serious national emergency, Governments, as in the late war, are compelled reluctantly to intervene either by direct order or by the educating of public opinion, in the direction of controlling the consumption of important commodities, of which oil is only one, in order to secure that supplies shall be used where the need is greatest. We may as well say at this point that it lies altogether beyond the scope of this paper to discuss or deal in any way with the action which the Government of any country may take, on grounds of national security against war, to store up beforehand reserves of oil or other minerals or munitions of any kind, or to enter into special commercial agreements and the like for such purposes. All that we need say from an economic standpoint is that the policy of any Government in such matters is obviously and necessarily influenced by the situation of the particular country in respect to the relative abundance or scarcity of such supplies or munitions within its own territory, or within its reasonable control in actual time of war. Further, since the economic situation in any given instance will not be created solely by nature but will be influenced by human skill and enterprise, the task of Government in preparing for national defence may be lightened or otherwise according to the extent

to which such enterprise prevails. One or two other points which are sometimes met with in economic arguments relating to oil and other minerals or commodities may be briefly mentioned, although in so far as they have validity they lie outside the scope of pure economics.

The first point is the right of a Government to limit the free exploitation of minerals, etc., in the interests of its own community, either in the present or to provide for the future, when the needs of that community may be greater than at present. We shall not pretend to dogmatize on this point, especially as Governments will do what they think right for their own people in such matters, whatever arguments economists or business men may advance. In any case an economist can hardly object to the principle that a country which has supplies of coal or oil or timber, etc., should exercise a reasonable discretion as to working and distribution, to secure to its own people some proper use of its own resources. The economic questions that will arise in such a case are more likely to be on points of detail as to fairness of price paid by the home consumer or whether Governmental action is unduly restrictive of legitimate export trade. The regulation of the felling and replanting of forest trees may be carried out in a way that might cause complaint at the moment from merchants with a good market calling for supplies, but to an impartial observer, who saw that more economical substitutes were thereby called into use and that the essential interests of consumers were being met over a longer period ahead, it would probably appear that the action of the Government was in the truest sense 'economic' and defensible on economic as well as other grounds.

The second point is whether a country which exports its surpluses of timber, coal, oil or other natural products in time of abundance can be said to be establishing a moral or preferential claim to draw on the resources of those other countries at a later date; on the ground that a benefit has been conferred which has enabled resources to be conserved that would otherwise have been drawn upon at an earlier date. This kind of argument is hardly to be treated very seriously, since trade is not as a rule conducted for philanthropic

purposes but for reasonable commercial gain. Great Britain has not sent her coal world-wide for any other reason than because it has been profitable to her coal and shipping interests to do so.

So far, then, apart from our incidental excursions into storage and other questions, we have seen something of the difficulty of making any estimate of future fresh production of oil that would be at all complete or afford anything more than a good general indication of potentialities—*i.e.*, for any long period ahead. Even as regards wells already in production varying opinions have been expressed as to their probable life and output, either under natural gas pressure or by pumping or by the modern intensive methods of the 'air lift,' etc. Obviously if we cannot say definitely, except for a limited period, what production may amount to, we have also many disturbing elements in any calculation of long distance requirements. For the near future, practical men can and do fairly balance up the probabilities and, subject to occasional errors, will arrive at working estimates on which they can base their production, purchase and sales. From the production figures we shall also get some idea of the difficulties of estimating consumption, for in the end production and consumption must approximately coincide. Looking at the world's production of petroleum at various periods, we shall find that, neglecting the earlier years that immediately followed Col. Drake's drilling at Titusville, Pennsylvania, in 1861, and taking the year 1880 as representing a period at which a substantial world trade in oil had been reached, we may usefully take note of the world's production of crude petroleum oil at certain intervals since then. In the year 1880 the total did not much exceed 4 million tons. Ten years later it was over 10 millions, and by 1900, the practical beginning of the 'oil age' (*i.e.*, when internal combustion engines were influencing oil consumption), the figure exceeded 20 millions. At the beginning of the war the total was well over 50 millions, and in the first year after the war had reached some 76 millions of tons. The next year, 1920, sent the total phenomenally to about 95 million tons. The 1926 figure was probably somewhere near 154 million tons, and 1927, according to a recent estimate by the editor of *Oil News* (London), may show only a moderate

increase over 1926. The significant recent years and events are: 1900, the beginning of the 'oil age'; the years immediately preceding and following the great war; the coming in of Californian, Mexican and East Indian production on a large scale, and of the Persian fields; the fluctuation of Russian and Roumanian production, and recent developments in South America. British Dominions make but a modest show, principally India, Trinidad, Sarawak, Canada and Scottish shale oil, amounting to a total of about 2½ million tons in 1925, with a somewhat better showing on the whole in 1926 and prospect of further increase in 1927 to perhaps 2¾ million tons; less than 2 per cent of the world's production. These figures relate purely to oil produced in actual British Dominions, excluding fields situated in other countries but worked wholly or partly by British enterprise. No oil prophet in 1900 would have ventured to predict that the world's annual oil production a quarter of a century later would be seven and eight times as great as at the earlier date. Few people would be bold enough to-day to suggest any such ratio of increase over the next 25 years. It is obvious that once consumption of a product has reached a point which is drawing near to what is called 'saturation', *i.e.*, to something like an average requirement for a given population, it is mainly to growth of population, apart from exceptional developments, that we may look for guidance in respect of an increased requirement. This is certainly not the only test, as we shall see later on, nor an infallible one, but it yields at least some general guidance. Most authorities are agreed that the indications of the moment, and of the last year or two, point only to steady and moderate increases of output and consumption, and that supply, demand and price alike are more stable than they have been for a long time past.

An interesting survey of the United States of America's "Supply and Demand" of oil, looking fifty years ahead, was published in 1925 on the basis of a report to the American Petroleum Institute. Whilst, as already stated, reviews for shorter periods are essential, the long view is also instructive, though many anticipations are likely not to be realised. The report in question made no attempt to construct a prophetic balance-sheet of supply and demand, but gave data and factors

showing tendencies of production, and possible interchanges in the relative uses of oil, coal, waterpower, etc. A 50 per cent increase of population and families in the United States over fifty years was allowed for, and the 'saturation point' of motor vehicles was taken at one per family or about 27,000,000 in the near future. More economical uses of fuel from engine improvements were looked for as an important factor. The report is, in any case, a valuable indicator to the number of avenues that must be approached and explored in any balancing of supply and demand of petroleum over a term of years.

As regards the general view taken recently by high authorities in the oil world as to the prospects of oil supplies continuing, it happens by a coincidence that we are in a position to quote two important utterances, delivered within a week of one another, the one in London on the 18th of January, 1927, by Sir John Cadman, the newly appointed Chairman of the Anglo Persian Oil Company, and the other, a week later, on the 25th of January, at Oil City, Pennsylvania, by Mr. George H. Jones, President of the Standard Oil Company of New Jersey, U.S.A. After scanning much oil literature for the purposes of this present paper, we can find no general pronouncements more weighty and at the same time more encouraging than these two, from which we extract or summarize the following passages, taking the two speeches in order of date.

Sir John Cadman, in the course of an address to the Royal Colonial Institute, London, on "Oil from the Empire Point of View," said: "It was reasonably safe to predict that the 'to-morrow' of petroleum, using the word 'petroleum' in the most comprehensive sense, would far outshine even the brilliance that today attended its achievements. Aviation, and particularly the adaptation of the airship and the all-metal aeroplane and flying-boat, would shortly herald the arrival of an important new stage in transport. Remarkable as might have been the marine use of oil during the last fifteen years, there were indications that by the development of new processes and of more economical methods they would shortly enter upon a much more scientific phase in the use of oil." Sir John continued: "What would be the ultimate fate of petroleum in relation, say, to the destiny of coal as a producer of power?" More than once he had recorded his convictions that, except within

narrow limits, what had been called 'the profound antagonism' of coal and oil was really a profound illusion. Even at present the two were very largely complementary, and he expressed disagreement with the view that the revival of coal in this country would sound the death-knell of the other industry. He thought they would find, as time went on, that, except where coal possessed advantages in its natural state, it would tend to embrace and adapt the technical processes already far advanced so far as petroleum was concerned. Again, processes still in the experimental stage might win through to proved success. Thus they would come to welcome the dawn of a new era in which comparable oil products might well be obtained from coal as from natural oil. Under those circumstances it would be possible for coal of the required characteristics—and by that he meant the great bulk of their potential coal production— to enter the refining plant in its solid form; by far the greater part of its calorific value and potential power would then be extracted and carried off in universally convenient liquid or gaseous form, leaving as a solid a residue of no heating value.

We summarise the following from the report of Mr. G. H. Jones' speech to the Chamber of Commerce, Oil City, Pa., on January 25th, 1927, in the *Oil and Gas Journal* of February 3rd. Mr. Jones remarked that oil was almost as important as food. Will supplies of motor spirit continue to be available or will United States citizens, to whom automobiles have become part of their daily lives, have to learn to walk again? Anxious inquiries of this sort have been sounded throughout the existence of the United States oil industry, more insistently than ever during the last five years. From 1900 onwards the demand for motor spirit has more and more dominated the situation. Out of an annual throughput in U.S.A. refineries of 813 million barrels, 283 millions become gasoline (motor spirit); 360 millions gas and fuel oil; 63 millions kerosene; 32 millions lubricating oils; the remainder is assignable to asphalt, wax and other products and a margin of waste. The United States annual production of crude petroleum has risen to about 750 million barrels for the past three years. Exports have been 130 million barrels and imports 80 millions. Produc-

tion in the U.S.A. has multiplied about ten times since 1900. The consumption of motor fuel in U.S.A. to-day is fifteen times what it was in 1913. Only revolutionary methods in refining and efficiency have made this record possible. Formerly only 30 per cent of crude was turned into gasoline. Now the entire barrel of crude is potential gasoline, since refineries are able to turn heavy oils into the lighter product. After remarking on the present state of above-ground reserve stocks of oil, the increasing cost of crude oil production and the cost of giving a luxury service of motor spirit to customers, Mr. Jones referred to the fact that oil wells are often drilled on a particular field in greater number than is actually necessary to drain a given area, to meet 'off-setting' requirements of leases and other conditions. He mentioned the recommendations of President Coolidge's Commission on conservation of oil and 'unit' operation of fields as compared with the competitive system. The U.S.A. has actually in sight 4,500 million barrels of crude—say, six or seven years' consumption. New reserves are being discovered very rapidly and such discoveries hitherto have not failed. Mr. Jones added: "Two or three years ahead the industry should function normally. Ten years or even a generation ahead I believe there will be adequate supplies of motor fuel. Our well oil will continue to meet essential requirements such as motor fuel and lubricants. I believe also it will remain the cheapest source of all these products. If in all this we are mistaken, if well oil fails or becomes an expensive supply.....we are already in a position to make motor fuel from oil shale and coal.....There is little possibility of our supply failing.....Well oil supplies cannot fail suddenly.....when the supply does begin to dwindle, as eventually it must, the decrease will be extremely gradual and other motor fuels will come into the market to supplement the gasoline supply."

One other American opinion, from an address delivered at Eldorado, Arkansas, U.S.A., as long ago as April, 1926, by a practical engineer (Mr. Earl Oliver) may be briefly cited (from *Oil Trade*, New York, February, 1927). Mr. Oliver, after referring to the opinions of philosophers and political economists on the functions of Government, said: "Efficiency

like morality cannot be legislated into being . . . . . Twenty years ago we used no science (on the oil field), now we are applying the accumulated wisdom of the ages. . . . . There is, I believe, no immediate serious danger threatening either the petroleum industry or the nation in respect to these resources, and yet it is only the part of wisdom so to conduct its business as to reduce the possibility of danger." Mr. Oliver went on to refer to the question much discussed in the U.S.A. as to 'unit operation' compared with competitive wells, and also to more efficient methods of extraction of oil from the wells, such as 'air, gas and water drives' and retention of gas pressure.

The opinions we have cited are of a generally reassuring nature, but they agree in regarding the oil problem as needing constant vigilance and to be approached by many methods. Sir John Cadman's reference to "the use of the word petroleum in its most comprehensive form"—*i.e.*, to include coal-oil and shale-oil as well, goes to the root of the matter, and both he and the President of the Standard Oil Company of New Jersey agree with other experts in looking to the possibility, however far ahead, of solid materials being made to provide liquid fuels when Nature's direct supplies of liquid oil begin gradually to dwindle. There seems a reasonable expectation, therefore, that with due vigilance, time and opportunity will be available for the gradual adjustment between the several branches of the oil problem as necessity arises. The probability is apparently that:

(*a*) Motor spirit can be ultimately 'taken care of' if necessary in whole or part by shale and coal derivatives, plus perhaps a proportion of 'power alcohol' from molasses and other tropical products.

(*b*) Lubricating oil will probably be obtainable from natural petroleum for a time and later from shale.

(*c*) Heavy fuel oils will presumably be largely replaced by coal substitutes either in liquid, gaseous or solid-lump or pulverised form.

(*d*) In any case electricity produced by water power or by cheap coal near the pit's mouth will tend to economy of oil and fuel generally.

It lies outside the province of the economist to describe the scientific, engineering and other technical problems involved; these matters will be dealt with in other papers by experts on those subjects. The economist's concern is: Can demand be met by supply? He therefore watches with interest the competition of various products to find their relative places in the market by virtue of quality, quantity and price.

Many writers and speakers have described what the world would be like if it were suddenly to be bereft of oil. Happily, according to the experts, we need not contemplate quite so serious a catastrophe as that. Nevertheless, even a partial and temporary failure would sufficiently tax our resourcefulness; we should be crippled at least and less efficient, though we should struggle on, like the hero in the ancient battle of Chevy Chase, who, "when his legs were hewn in two, still kneeled and fought on knee." Lubricating oil for machinery in ships and factories, motor spirit for essential services, with temporary restriction of luxury uses, and fuel for engines of Diesel type would have to be the objects of first attention.

Our rambling survey has now given us some idea of the total production of petroleum, and has shown incidentally that Great Britain's direct contribution to the world's supplies, though happily increasing, is but a modest one, less in fact as already stated than two per cent of the total. We may next glance at the geographical distribution of the principal oil-fields and then make some approximate comparison of that situation with the geography of oil consumption, more particularly in British dominions. One of the oil problems of the war was the saving of transport, including the voyages of oil-carrying vessels (tankers), and much attention was given to the practicability of making supplies of oil, etc., from nearer sources than those from which in some cases they were usually drawn. At normal times, manifold reasons of grade and quality, old established trade, return cargoes, etc., account for what, on a superficial view, might seem unnecessarily 'long hauls.' Oil from the U.S.A., from the Dutch East Indies, from Persia, and other great fields, finds its way not only to domestic and near-by markets as one would naturally expect, but far beyond. One may light upon a barrel of American kerosene in a shop in a remote village of China, India, or Jugo-Slavia, or find

stocks of American lubricating oil available for ships in the seaports of the world, far remote from its place of origin. Similarly, coal supplies from Great Britain, U.S.A., India, South Africa, and Australia are to be found wide-spread for bunkering and other purposes. A few years ago Canada regularly sent supplies of coal to San Francisco; later on Canada received oil from California. The President of the Standard Oil Company of New Jersey, in the speech referred to above, mentioned that the U.S.A. is not only, as all the world knows, the greatest oil producing and oil consuming country, to the extent of about 70 per cent of the world's total, but it also both imports and exports petroleum in considerable quantities. And, in present circumstances, it is for the general benefit not only of American trade but of the world's oil-consumers that this should be the case. A few years ago the U.S.A. made use of her own oils to a very large extent for heavy fuel as well as for the lighter fractions. Today America, more profitably for herself and the world, imports crude oil from Mexico and elsewhere for heavy fuel and uses most of her own lighter grades to produce a greater quantity of motor spirit, etc. We may naturally find the same situation prevailing to some extent, but in lesser degree, in respect of the world's oil-fields generally. There has been a growing tendency in recent years for crude oil to be transported considerable distances by pipe line on land or by sea voyages, long or short, in tankers to refineries situated near great markets, as compared with the older practice (which still largely prevails) of refining in the neighbourhood of the oil field or of ports comparatively near by.

Very approximately the world's oil production in 1926 occurred geographically as follows:

	Tons
American Continent (i.e., U.S.A., Canada, Central and South America, and West Indies)	130,030,000
Europe (mainly Russia, Roumania, and Galicia)	13,000,000
Africa (practically Egypt only)	170,000
Asia and Australasia (principally India, Persia, Dutch East Indies, Sarawak, and Japan)	10,800,000
Total (tons)	154,000,000

The following table shows recent progress in oil production in British Dominions (in long tons), including shale oil, but excluding Trinidad asphalt:

	1924	1925	1926
United Kingdom	208,269	229,668	197,463
Canada	24,310	22,968	45,465
Trinidad	435,839	579,916	637,423
India	1,200,878	1,202,333	1,195,779
Sarawak	550,704	595,115	603,870
Total (long tons)	2,530,000	2,630,000	2,680,000

On the subject of oil statistics, particularly of production, we may here remark that there is great lack of uniformity in the demominations of quautity that are adopted by various compilers. Crude and heavy oils are usually stated in barrels, which are often converted to tons by a very approximate number of barrels per ton. Confusion arises also from the employment of metric tons in some cases and 'long' tons in others. The two tonnages are sometimes found together in the one statement, where more than one source of origin is involved. Refined products are frequently expressed in gallons and here again tonnage may be deduced by exact or merely by average methods. Fortunately for our present purpose where we are only concerned in broad comparative results, a few inconsistencies of this nature do not affect any main argument or general conclusion.

When we come to look at figures relating to the oil consumption of particular countries per head of population we shall be struck by the very wide divergencies thus exhibited. The U.S.A., for example, probably consumes seven or eight times as much petroleum per head of population as, let us say, Great Britain or Australia, and naturally far more per head than is the case with great agricultural and village populations such as those of India and China. For our present purpose it is hardly necessary to analyse in any detail the resaons for such divergencies, but a few of the principal general considerations leading to a greater or less consumption of petroleum products per head of population may be stated. Whilst the actual

comparative percentages at any moment are relatively unimportant, the more or less permanent underlying conditions, on the hand, and the tendencies towards changes and developments on the other hand, must necessarily be taken into account in any consideration of the probable increase of oil consumption in any particular country. It goes without saying that in a highly developed country, however widely distributed over the world some portion of its fuel production may be, the main consumption will be at home—*e.g.*, as in the case of coal in Great Britain, oil and coal in U.S.A., etc. America having large supplies of both oil and coal naturally uses either according to relative cost, efficiency and accessibility, and may change over from one to the other, where such changes are practicable and advantageous. Accessibility to an advantageous type of fuel is the first consideration. We need not be surprised, therefore, to find that out of a world's total of motor vehicles, estimated on January 1st, 1926, at upwards of 26 millions, the U.S.A. owned more than 20 millions, Great Britain 1½ millions, Canada three-quarters of a million, Australia about 350,000, India 83,000, the Dutch East Indies 45,000, etc. Great Britain leads the way, however, in 'motor cycles,' for reasons perhaps of their economy of fuel as compared with motor-cars, also the distribution of its urban and suburban population and the generally excellent state of its roads, etc. Great Britain still uses some 20,000 steam-propelled vehicles (of the heavy type) on the roads, and there is no reason why she should not continue to do so. The Chinese and Indian coolies respectively will continue for a long time to come to use their bullock carts, wheelbarrows and 'rickshaws'. Nor has the horse in any country yet joined the 'Dodo' in the limbo of extinction. Available railways and tramways, variously propelled, the condition and extent of roads, water power, distribution of population as between town and country, electrical developments, are all factors in our problem. Where there is a great network of railways in a developed country there is less need for motor transport; though in many such countries there is already considerable competition between rail and road, and motor vehicles are likely to be used to some extent to the possible delay of railway extensions. This is also the case in such countries as Irak and Persia, where with limited railways, motor transport has

superseded to some extent the more ancient camel and mule caravans, and will continue in use even when railways, which will almost certainly run on local oil, are much more developed than at present. Powerful six-wheel motor vehicles for passengers regularly traverse the desert routes from Damascus to Bagdad, and from Algiers and Tunis far down into the Sahara. More and more ubiquitous, therefore, will the motor vehicle and the aeroplane tend to become, and in many cases we must expect to find for a long time yet that the growth of population will not be the only criterion of the increased use of petroleum. Nevertheless, let us see what sort of population figures we have to deal with in British dominions. The population figures in 1921 were approximately as follows:

		Population
I.	Great Britain, Ireland (North and South), Gibraltar, and Malta	47,600,000
II.	Canada, Newfoundland, West Indies, British Guiana, and British Honduras	11,150,000
III.	India, Ceylon, Singapore, Malay States, Hong Kong, Sarawak, and Cyprus	332,650,000
IV.	Africa (South, East, West and Central, excluding Egypt), Zanzibar, and Mauritius	50,400,000
V.	Australia, New Zealand, Fiji, Papua, and British New Guinea	7,800,000
	Total (population)	449,600,000

The rate of increase of the numbers of the people is very variable in different parts of the British Dominions. In India, for example, the increase in ten years, from 1911 to 1921, was about 1 per cent—viz., 315,156,396 to 318,942,480. In England and Wales the increase in decennial periods before the war was variable but ranged around 12 per cent. In Canada the increase, between 1911 and 1921, was about 17 or 18 per cent. We need not stop to consider in connection with oil, as our standard economists used to do with respect to food supply, what limitation population might have to impose upon itself. That will be settled by food supply and other considerations.

We may now proceed to calculate approximately the oil consumption of British Dominions from such statistics of imports, exports and local production as are available. For

this purpose we may group the British Dominions geographically on the same lines as in the 'population' table given above. A rough estimate of consumption of oil products gives the following results:

		Tons
I.	Great Britain, Ireland, etc.	6,370,000
II.	Canada, Newfoundland, West Indies, etc.	2,470,000
III.	India, Ceylon, Malay States, Hong Kong, Sarawak, etc.	2,660,000
IV.	Africa (British), Zanzibar, Mauritius, etc.	250,000
V.	Australia, New Zealand, Fiji, etc.	1,000,000
	Total (tons)	12,750,000

These figures in some cases include asphalt, pitch, wax, etc. At the time of writing (March 1st, 1927) it is not practicable to take out all the figures up to December 31st, 1926. That year has been taken for Great Britain and Canada, and 1925 for the other groups. The remark already made as to the approximate nature of oil statistics applies also at this stage, as there are divergencies of method in compilation in different countries and in converting from gallons to tons. In arriving at a 'consumption' figure, allowance has been made where necessary for the proportion of local products used in the country of origin. The imports into Great Britain include about 2,000,000 tons of crude oil, mostly from Persia for refining. Great Britain's supplies of 'bunker oil' to shipping at her ports amount to nearly one million tons per annum. Such supplies are, of course, not wholly for British ships. For our main purpose of reviewing oil requirements of British Dominions in total we have put together all types of products. It may be useful, however, to note in the case of one group, say, No. I (the largest consumer), by way of illustration, how the total is divided over the different kinds of product. We therefore give for that group the imports of all kinds in gallons. Imports into Great Britain of petroleum products in 1925 and 1926 (as given in London *Petroleum Times*, January 15th, 1927) are shown in the Table on page 18.

Ten years earlier the total import was in the neighbourhood of 450,000,000 gallons, but by 1918 the figure had already reached 1,300,000,000 gallons. The imports of oil products into Great Britain in 1926 were increased considerably through the coal strike. A detailed study of the movements of oil

Imports of petroleum products into Great Britain.

Product	1926	1925
	Gallons	Gallons
Lighting oil	201,950,966	141,649,425
Motor spirit	562,176,619	404,834,226
Lubricating oil	91,810,250	84,361,784
Gas oil	117,042,798	72,652,528
Fuel oil	398,443,393	334,489,850
Crude oil	538,239,606	569,082,169
Other sorts	3,272,324	6,231,383
Total imports (gallons)	1,912,935,956	1,613,301,365
Total value of imports	£46,795,161	£39,512,451
Total exports (gallons) Excluding re-exports.*	168,435,455	129,593,938

*The total 'imports' given above are 'gross.' To arrive at the 'net' figure, the 're-exports' should be deducted, amounting in 1926 for all products to 31,554,492 gallons, and in 1925 to 62,968,313 gallons.

across the seas from sources of supply to various consuming centres is hardly necessary for our present purpose, but we may glance at the general position. There is, of course, a considerable movement of oil coastwise for the whole of the American Continent on both the Pacific and the Atlantic sea-boards, from South America and Mexico to the U.S.A. and to some extent to Canada; also from U.S.A. Gulf ports to New York and other centres. Westward, products of a considerable tonnage find their way from the U.S.A. to Japan, China, Australia, New Zealand and India. Eastward, the flow is from North and South America, Mexico and Trinidad to Europe and to some parts of Africa and Asia. Trinidad sends asphaltic material also to the American markets. Persian oil finds its way to local and eastern markets, also to Great Britain and to some extent to other parts of the Continent of Europe as well as to Mediterranean ports. The Dutch East Indian production also has its markets locally as well as in India, China, Australia, Africa and Europe. As is well known, crude oils vary greatly in character and in their yield of different types of refined products. Consequently, some part of the needs of a particular market must often be met from a distance. The development of production in Asiatic fields

is likely to effect some gradual reduction in the 'long hauls.' We can, however, hardly contemplate in the near future anything approaching a complete balancing of supply and demand in any particular geographical area outside, perhaps, of the American Continent taken as a whole. A little farther ahead, as we shall show presently, we may draw nearer to a local balancing of supply and demand. Great Britain, India, Australia, New Zealand and Africa draw upon most of the big oilfields of the world, whilst Canada naturally completes her demand from other parts of the American Continent. The extent to which supplies of solid oil-bearing material may be available in British Dominions, and the degree of progress that has been made to date, scientifically and technically, in the processes of extracting oil from coal, etc., will be fully treated in other papers that will be laid before the Congress. Subject to what those papers may tell us, we may assume the availability of considerable raw material in British Dominions. Experience with some extraction processes indicates that successful working on a commercial basis may be confidently anticipated. In other instances time will be needed to show whether what is practicable on the laboratory scale will be also possible commercially. On the whole the review of progress is of a distinctly encouraging character. The subject is one not likely to be neglected either by commercial interests or by scientific and technical experts. Our own Institution of Petroleum Technologists does its part in keeping the subject to the front. Birmingham University and the British Government's Fuel Research Laboratory deserve honourable mention for the work they have done and the manner in which they have kept abreast of developments. In all probability the natural petroleum supply has not yet reached its zenith, and will therefore for some time to come 'take care' of demand on the present scale plus some proportion at least of the world's increased requirement for fuel products in liquid form—*i.e.*, leaving out of account any increase in the use of solid fuel or gas, water power, etc. The balance of any increased demand for liquid fuels beyond what natural petroleum may be able to meet, will require to be provided from shale oil, or coal derivatives, the latter being obtained by either low temperature carbonisation, hydrogenation or other processes.

In so far as actual need in the market develops for shale and coal products, they must come in on an economical basis and gradually become more remunerative as their costs of production are reduced by working on a larger scale and with improved methods. Shale oil products are of course no new feature in the market, the Scottish industry having had a longer life than natural petroleum—*i.e.*, in its modern phase. Australia and Canada on varying scales have experimented with production of that nature, but the time has not been quite ripe for much success. The experience gained will be valuable, however, in the situation which may arise later. We shall have to prepare beforehand, as America appears to be doing, in order to turn to such sources of supply when economic pressure necessitates.The price problem of the shale industry, in its competition with natural petroleum, often or perhaps usually, has lain in the marketing, profitably or otherwise, of its by-products. Low-temperature carbonisation of coal has to contend with problems of working costs, varying for different grades of coal. One of the problems of this process is the profitable disposing of solid semi-coke residues. It would obviously be uneconomical to produce a certain quantity of liquid fuel, if in consequence a vast tonnage of solid fuel were left on hand as a drug in the market. Hydrogenation or Berginisation processes will have to contend at the outset with working costs for plant, etc. If success is achieved in reducing coal to liquid and gaseous form with only a small percentage of solid residue, the next economic stage will be to see whether the cost of refining the liquid will present more difficulty and therefore be more costly than that of natural petroleum. All these considerations point to the possibility of natural petroleum continuing for some time at least to have the more remunerative share of the market when liquid fuel from other sources comes in as well. On the other hand, the costs of production of natural petroleum, as pointed out by the President of the Standard Oil Company of New Jersey and by others, are greatly on the increase. Colonel Drake in 1861 'struck oil' at 69 feet. To-day the world's large production is coming from wells of varying depths, perhaps on an average from 1,500 ft. to 4,000 ft., necessitating obviously much expense for drilling work, casing, drilling tools and control equipment.

Oil experts are looking to the possibility of quite a number of wells at 5,000 ft. or thereabouts. As is well known America already has a few wells deeper than 7,000 feet. In California, according to recent reports, there is one well drilled to 8,000 ft. at a cost stated to exceed £30,000, without assured production yet being obtained. Obviously increases of this kind in the cost of the winning of natural petroleum, unless balanced by great production and high grade of oil, may tend to some extent to even up the competition with oil derived from shale and coal by the process of retorting, hydrogenation or other intensive methods. Time will show.

A question of very deep interest to every large oil-consuming, or more generally fuel-consuming, country or group of countries such as those that form the British Empire, is whether the separate units or the aggregate of units can be made self-supporting. As we have seen, this does not happen at present owing to the fact that oil of varying qualities has not been placed by Nature in all cases near to where great centres of population have arisen. The near future of oil distribution is not likely to render the several parts of the British Empire self-contained. Let us take comfort; our ships and our sailors will play their part in transport to enable the oil industry to sort out and distribute its goods to its far-flung consumers. In our ancient 'corn in Egypt' illustration, the Governor of the country had to deal with his problem as a self-contained one. He had to dispense some part of his hoarded reserves to meet the requirements of the famine-stricken area of Syria, but there was no assured source of supply to which Egypt could have recourse from any near-by country with more equable rain-fall or less dependent on the regular recurrence of a fertilising river flood. Nor presumably had the administrator at his command what civilisation has since provided—viz., an abundance of technical talent for the construction of river dams and the development of irrigation. Had there been either neighbouring supplies to draw upon, or the possibility that technical skill and enterprise might reduce the period of lean years, the wheat shortage would have been met, not by one method only, but by three at least—viz., storage, import, and the stimulating of home supplies. By these methods, then, and particularly the two latter, will the oil

and fuel problems of British Dominions, as of other countries, continue to be met. We have referred already to the many agencies and activities—commercial, scientific and technical—that are at work on this problem throughout the world.

Turning back to the problem propounded in the first paragraph of our paper, we have now seen that on an economic basis British Dominions, today, in face of their petroleum demand of about 13,000,000 tons, or probably more, if we could get all figures up to date, possess a home production of nearly 3,000,000 tons, not all of which is used in British Dominions. Out of the balance of eight millions, a considerable contribution is provided from enterprises more or less controlled by British organisations in other countries. The balance is met from the world's large oil fields generally. All this involves many voyages of tank steamers to give each consuming unit the proportion of the particular products required. Now as to the future, much as we dislike anticipations of too hypothetical and speculative a character, let us assume that twenty years hence the British Empire demand may have increased to, say, 15 or 16 million tons of liquid petroleum products. If we suppose, and this is a leap in the dark as well as improbable, that in the course of twenty years the world's natural petroleum supplies may have dwindled to very modest dimensions, each great consuming country in the world will be doing its best to meet its own requirements from self-contained resources of coal, shale, recourse to water-power, etc. What, then? The British Dominions, having great resources of coal and shale in Canada, Australia and South Africa, and coal with moderate shale beds in Great Britain, would have to convert annually perhaps 150 million tons of coal and shale into liquids, gases and solid residues. We may assume, as America does in her own case, that our resources of solid materials would meet this demand for a long time to come. We should still have some oversea transport of oil products, but each main unit of the British Empire would be to a greater extent self-supporting in this respect than is the case to-day, though possibly on a higher level of market prices. Natural petroleum, notwithstanding all the 'long hauls' we have spoken of, has great advantages which we may hope and believe will continue to be available. The period of their enjoyment will be pro-

longed in proportion as we use such resources wisely and without extravagance. This is not the only occasion on which the present writer has had the privilege of drawing attention to this subject. In his review of "Oil Problems of the War", in April, 1919, as the then President of the Institute of Petroleum Technologists, he summed up the opinions of oil experts with whom he had been in contact on both sides of the Atlantic, and he returned to the subject a year or two later, in *Brassey's Naval and Shipping Annual*, 1921-22, Chapter XIV., "The World's Resources of Petroleum Fuel Oil." The principal points emphasized on those two occasions were:

(1) Expectation of a large increase of demand. (2) Prospect of meeting demand by supplies of natural oil. (3) Economy in use and avoidance of waste. (4) Development of coal, shale and vegetable oil products. (5) Great field for scientific and technical skill and co-operation between producers and users of fuel, engine designers, etc.

That many activities are at work that will ultimately solve the fuel problem is evident, also the best results will be obtained by the continued co-operation of commercial, scientific and technical forces. But Governments, especially so long as the nightmare of possible warfare disturbs their rest, will keep a watchful eye on their own situation of preparedness in this matter and the utilisation of alternative supplies.

Every nation has its informal intelligence department, not necessarily in the Government sense, but in the vigilance, enterprise and co-operation of its citizens. Mining industries in general and not oil alone are rich in this—viz., that they require for success an array of co-ordinated talent, scientific, technical and commercial. The discoverers of the earth's mineral resources are necessarily travellers and of an enterprising type. They have to go far and wide as practical men of affairs, with eyes wide open and alert, receptive minds. Much of the general scientific and technical knowledge and experience which they gather is used not only for commercial enterprise, but also becomes eventually, through scientific institutions, etc., part of the world's common stock. If there were 'seers' specially inspired in ancient days, there are in a very real and practical sense 'seers' to-day, pursuing research, exploration and invention both for enterprise and discovery's

sake, and also for industrial progress. The results are already considerable. A glance at the technical literature that will be before the Congress, or is available in publications by the Governments of British Dominions or by scientific societies and commercial organizations, is encouraging. Particularly one might mention by way of typical illustration some of the Canadian and Australian reports on coal resources, water-power, etc. The Congress will no doubt consider many ways by which in the several British Dominions, preferably by voluntary and unofficial effort, there may be brought together, focussed and co-ordinated from time to time, even more fully than at present, for the benefit of commercial enterprise or the informing of Governments, the knowledge and experience that our explorers, scientists, engineers and many others are daily acquiring whilst going about their ordinary activities in various parts of the world.

We have spoken above of 'solving the fuel problem'. In a sense no final solution will probably take place. All that is likely to happen is that the difficulties appertaining to finding an adequate supply of the various fuels that are in vogue or needed in given circumstances will be surmounted by various means for the time being; opening up a vista of new problems requiring fresh research and enterprise. A generation or two ago British writers on economics were much exercised over the possible early exhaustion of coal supplies. Subsequent investigations and discoveries have shown that coal exists in far greater abundance and more widely distributed than was then supposed. Nevertheless supplies of coal are not inexhaustible and in some countries will have to be won at greater cost from deeper sinkings. But there is enough for many generations to come, and in the interval scientific research will still be at work and mining congresses will not lack subjects for discussion. In the case of oil, men of science are only now beginning to investigate the conditions under which it has been produced in Nature, and to take observations to find out, if possible, whether Nature has ceased its productive activities or not in that connection. Meantime, as we have seen, it is to the derivatives of coal and shales that experts are looking for fuel if natural petroleum ultimately proves inadequate. Generally speaking, whilst we

are bound to make prudent provision reasonably far ahead against possible catastrophe, and not to penalise our own or later generations by extravagance and waste, it is possible to be over anxious about problems which posterity may be better equipped than ourselves to deal with. Wood, coal and oil still play their respective parts. We need not speculate here upon possibilities hardly yet dreamt of in the development of natural forces for heat and propulsion.

Oil may at least claim this—viz., that it will have served the world with high efficiency and pointed the way to coal being utilized in more economical fashion than by the combustion of a raw material in the solid state. No need can yet be foreseen for literary skill to employ itself in writing an epitaph for the age of oil.

The author of this paper desires to acknowledge his obligations to the High Commissioners and Agents-General of British Dominions, to the Institution of Petroleum Technologists and the Imperial Mineral Resources Bureau for valuable statistical information.

Note.—Discussion on this paper appears on page 195, following the paper on *Petroleum and Natural Gas in the Dominion of Canada.*

PROGRESS AND PROSPECTS OF OIL PRODUCTION

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To make any estimate of what production of oil could be obtained from sources within the Empire is obviously a very difficult task, especially when so much of the most promising areas has been merely explored but not exploited; but fortunately a great mass of data is available, and it should be possible to give some idea of the possibilities of production from each field for the next few years.

For this purpose the various areas may be divided into:

A.—Producing fields.

B.—Oilfields or supposed oilfields prospected but not producing.

C.—Fields containing retortable material.

A.—Producing Oilfields

The list of producing oilfields is a short one, as follows:

(1) *Burma.*—This country has been worked successfully for petroleum since 1886, and produces a paraffin-base oil of very high quality. There are seven separate fields that are at present being worked, but of these only two are giving large productions. It does not appear probable that any new field will be discovered, though active prospecting is in operation, and there are some localities still to be tested.

Production for the whole country has probably reached, if not passed, its peak. It should, however, be possible to maintain a large production for many years to come.

(2) *Assam.*—This province has been producing oil for many years, but the production has only recently become important. The oil is of good quality and contains a high

percentage of paraffin waxes. Several new presumed fields are being prospected, and some are being tested with the drill. It is to be hoped that production will increase gradually and steadily as it is required, and if several new areas are found to contain oil in commercial quantity, there may be a considerable increase in the output of the province. On this point it is impossible to make any definite statement.

(3) *Punjaub.*—In spite of much intensive prospecting and the testing of several areas by experimental drilling, only one producing field has been proved, and there seems to be very little prospect of further discoveries.

Production is small, and is not likely to be increased to much greater proportions. The total production for India is at present about 1,100,000 tons.

(4) *Trinidad.*—This Colony has established its position as the second most prolific source of petroleum in the Empire. The production has steadily increased to upwards of 650,000 tons per annum, and there is every prospect of the increase continuing. One estimate puts the last year's production as high as 800,000 tons. A large part of the western districts of the Island is now proved oil-bearing land, but there are still many localities in the southern and central districts where no organized attempt has yet been made to test promising geological structures. Furthermore, no really deep drilling has been undertaken, even in the proved fields. The latest results of experimental drilling give promise of several new fields being developed successfully.

Many different qualities of petroleum are obtained, from a heavy and sulphurous asphaltic type to a light paraffin-base oil. By far the greater bulk of the oil at present obtained is asphaltic, but it is frequently of fairly low specific gravity, containing good percentages of light oils.

Taking everything into consideration, the Colony can be counted upon for a production of about 700,000 tons per annum for many years to come, and it is quite probable that an increase to one million tons will be attained with deeper drilling and the opening up of new fields.

(5) *Sarawak.*—The production of petroleum is at present approximately 600,000 tons, nearly all from two fields. There

is every prospect of this production being maintained for many years, and it might be considerably increased by the bringing in of new fields.

(6) *Canada.*—The eastern oilfields in Canada have been producing oil for many years, but the production has been falling off slowly and steadily. It is now less than 30,000 tons per annum, and there seems to be very little prospect of new fields being discovered. Gas production is still good. Ontario provides the chief fields. but there is a small one in New Brunswick.

It is to the western fields that Canada must look for future supplies, and the position in Alberta is at present very interesting. Small fields with great production of gas and a little heavy oil are being developed on the prairies near Wainwright and Ribstone, but it is to the foothills of the Rocky mountains that attention is chiefly drawn.

One well in Turner Valley has been producing for more than two years upwards of 500 barrels a day of light gasoline, and other wells in the neighbourhood bring up the daily production to about 1,000 barrels. The gasoline is condensed from a very strong flow of wet gas, under its own pressure and at the low temperature due to the sudden expansion of the gas. There are prospects of extending the productive area in this valley, but it is realized that the true source of the oil has not yet been ascertained. Drilling in other localities in the hope of discovering a supply of oil of a more normal character is proceeding, and will be intensified in the near future.

There are two theories with regard to the oil—the first that it is of Devonian or even greater age, the second that it is Cretaceous. The evidence viewed on a large scale favours the latter theory, though the oil may be actually found in older strata.

The production of oil of western Canada can be expected to increase, perhaps very greatly, without taking into consideration such localities as Fort Norman, which is too far away from markets to be of practical importance at present.

The total production of Canada is now about 70,000 tons per annum, but this, as stated above, may be increased greatly.

(7) *Barbados.*—This colony has been prospected diligently for oil, and there have been many experimental wells drilled without any striking success. At present there is a small production of a very good quality of oil, but the supply is not yet sufficient for local requirements. No great increase of production is to be expected.

Considering all the producing oilfields of the Empire, the total supply of free petroleum is little more than two and a half million tons per annum, and so far as can be predicted at present production is not likely to exceed three million tons. New discoveries may make it necessary to amend this estimate, but for the present three million tons may be taken to be a maximum, which can certainly be achieved by energetic development of the present known sources or the discovery of new sources.

It is unnecessary to point out how ludicrously inadequate such a total supply is compared with the needs of the Empire. The result is that there is too great a dependence upon foreign sources, which may conceivably not be available in certain contingencies. British capital is largely engaged in the development of oilfields and the production of oil in foreign countries, and without a certain amount of control so arranged for, the situation would be parlous; but the endeavour to make use of sources indigenous to the mother country, the Dominions and Dependencies, becomes of paramount importance.

B.—AREAS PROSPECTED OR BEING PROSPECTED

That signs of petroleum are very widespread is a commonplace, but it is not perhaps fully realized in how many countries petroleum exists, and yet cannot be obtained in commercial quantity. In many such cases the search for oil may be foredoomed to failure from the start, but where there is even a remote possibility of success, prospecting and geological examination are justified. The optimism, however, that continues the search after all hope of a successful result has been shown to be unjustified, is merely a deplorable waste of energy.

A pooling of information might go a long way towards obviating renewed attempts to find oil where conditions have

been proved to be definitely unfavourable, and it is with the view of bringing about such a pooling in the interests of Imperial development that in the following notes several countries are dealt with that might otherwise be disregarded.

(1) *Australia.*—The value that would naturally attach to an oilfield in Australia has been the cause of many enterprising attempts, and prospecting and drilling are still proceeding in certain quarters.

In Queensland the oil-bearing stage has undoubtedly been reached in Secondary strata, but so far no geological structure capable of concentrating and retaining petroleum in quantity has been detected. Gas in considerable quantity has been struck, and small traces of heavy residual petroleum have been encountered here and there. There would appear to be little or no chance of developing an oilfield.

In New South Wales there is just a possibility of finding petroleum beneath the torbanite-bearing strata in one or two small domes, but the prospect of proving a commercial field is poor.

In the Tertiary belt of South Australia much work has been done, but once again favourable geological structures are wanting, so no success can be expected.

In Western Australia and the northern territories, in spite of extensive prospecting, no favourable area has been discovered.

The greater part, and especially the central part, of the country is formed of igneous, metamorphic or very old sedimentary rocks from which no production of petroleum is possible.

(2) *New Zealand.*—The presence of oil has been known near Taranaki and New Plymouth for a number of years, and there have been several attempts to develop oilfields. One of them promised to be successful, but finally resulted in failure. Another attempt is now being made. There is very little published as to the geological structure and the nature of the strata from which it is possible to judge of the prospects of a commercial oilfield being developed.

For the present New Zealand must be classed as a territory that has been unsuccessfully prospected.

(3) *Nigeria.*—Samples of asphaltic oil were first brought from the coastal belt in Nigeria in 1906, and later a company

was formed to prospect and exploit the field. It was found, however, that the oil occurs in a shallow strip of Tertiary rocks lying upon granites and metamorphic strata, and that there are no post-Tertiary folding structures capable of concentrating petroleum.

Later geological prospecting merely confirmed what was known before, and all attempts to develop an oilfield have been abandoned.

(4) *Gold Coast.*—Much the same conditions as ascertained in Nigeria apply to the Gold Coast; though seepages of oil are known there is no prospect of obtaining commercial production.

(5) *The Sudan.*—Very little geological prospecting for oil has been undertaken in this area, though the possibility of small fields along the Red Sea littoral has been considered. The geological Survey of the Soudan has made it clear that neither strata nor geological structures are favourable for oil formation or conservation. It is to be feared that there is no reasonable hope of finding an oilfield in this territory.

(6) *British Somaliland.*—This is another case where oil undoubtedly occurs in a shallow formation lying upon much older strata. Several experts have visited the area, but have pronounced unfavourably upon it. To undertake serious development work would appear to be useless.

(7) *Uganda.*—This country has been fairly exhaustively prospected, and has been proved to be formed chiefly of igneous and metamorphic rocks. In the great Rift valley, and particularly on the eastern shores of lake Albert, seepages of asphaltic petroleum are known from what are apparently Tertiary strata deposited in the rift. In such circumstances, however, it is practically impossible that any folding structures capable of concentrating and storing petroleum can have been formed. Further prospecting may be undertaken, but will almost certainly yield the same results.

(8) *Nyassaland.*—Geological conditions here are similar to those in Uganda; there appears to be no hope of finding an oilfield.

(9) *Newfoundland.*—Oil of excellent quality can be obtained in the northwest of this Colony, and more than one attempt has been made to develop a field, but always without success. The oil occurs in Palæozoic strata, but no really favourable structures have been detected. It is possible that a small and shallow field yielding good oil in small quantities could be established, but at the best it could only be of local importance.

(10) *South Africa.*—The occurrence of cracked oils naturally distilled from carbonaceous strata by the heat of igneous intrusions in many localities in the Karroo (Triassic) series has been the cause of much prospecting and drilling. Gas also has been encountered, but not of the nature typical of oil wells. All the drilling has been unsuccessful, though in dolerite dykes and sills and at their margins, where carbonaceous strata are not far distant, signs of cracked oil are frequently in evidence.

In the zone where folded structures occur and dolerite intrusions are absent, there are no reservoir rocks of sufficient porosity to contain petroleum in quantity, though the strata may be slightly bituminous. Throughout most of the area occupied by the Karroo system the strata are almost perfectly horizontal, and thus afford no structures capable of concentrating and containing petroleum.

South Africa may, therefore, be added to the list of countries that have been prospected and found wanting.

(11) *British Guiana.*—The occurrence of seepages of oil, or masses of sticky, asphaltic oil driven ashore on the northern alluvial flats of British Guiana near the mouth of the Orinoco, has frequently called attention to the possibility of an oilfield being concealed by superficial deposits in that region. Geological examinations have yielded only negative evidence, and the consensus of opinion seems to be that though it is possible that oil-bearing rocks of late Tertiary age may be present beneath the surface in the extreme north of the Colony, there is little probability of suitable structural conditions to concentrate petroleum. In fact the environment may resemble that of the coastal belt of Nigeria and the Gold Coast, and thus be unworthy of attention as a possible oilfield.

(12) *British North Borneo.*—The proximity to the prolific oilfields of Dutch Borneo, where oil of very high quality is produced, naturally called attention to this Island.

Very extensive geological work has been done in recent years in British North Borneo, and some drilling has given very hopeful indications, if no really good producing well has yet been drilled.

Geological structures, such as have been carefully mapped, are not wholly favourable. Large anticlines with a regular pitch and hardly any arrestment of pitch have been delineated and shown to be oil bearing, but the lack of dome structure has prevented any great concentration of oil.

In other districts favourable structures of smaller size have been recognized, but the stratigraphical relations have not been ascertained with certainty, and the presence of oil has not always been proved.

Thus, though the area still contains many prospects that have not been tested by the drill, the outlook is uncertain, and British North Borneo must be regarded as an unproved, but still possible, field for exploitation.

(13) *New Guinea.*—This is another territory that has received attention in recent years. A great deal of geological prospecting has been done, and a certain amount of drilling, without any oilfield of importance being discovered. Seepages of oil are known in many localities, but geological structures are small and narrow, and the strata dip often very steeply.

The productions of such wells as have been drilled are meagre, but the quality of the oil is good.

In what was formerly German New Guinea there appear to be better prospects than in Papua.

Much pioneer work remains to be accomplished before it can be decided whether the Island is likely to become an important source of petroleum supplies or not.

(14) *Canada.*—There must be very few, if any, localities in Canada where there is a chance of developing an oilfield that have not been prospected geologically, but there are a number of possibilities that have not yet been tested by the drill.

Of these the areas of greatest promise are on the flanks of the Rocky mountains, particularly in the foothills of Alberta. On theoretical grounds alone there are several structures which have been partially, but not effectively, tested before, that are worthy of careful drilling to greater depths than have been explored. It is not unlikely that fields of considerable size and importance might be developed, but all such exploitation is necessarily speculative, and the lack of suitable reservoir rocks may once again militate against the accumulation of any large supplies of petroleum. The year 1927 may see several promising areas put to the proof, and may decide whether the hopes of geologists and prospectors are well founded or not.

(15) *Great Britain.*—It is perhaps unnecessary to allude to the attempts to prove an oilfield in Great Britain. Eleven areas selected by geologists experienced in petroleum work on the data furnished by the maps of H.M. Geological Survey have been tested, and only two wells have produced oil in anything like what might be described as commercial quantity. The Hardstoft well in Derbyshire has continued to produce oil of good quality, but subsequent wells drilled near it have been unsuccessful. The numerous slight shows of gas and residual oils encountered in other wells proved that oil-bearing conditions had existed at one time, but that the oil has been dissipated or adsorbed, and only the merest residues left. The Hardstoft oil is a naturally filtered product that has its source probably far above where it was struck.

Most of the experimental wells were carried to quite sufficient depths, and one or two were carried deeper than was necessary, but in one case, and this, curiously enough, was the most promising of all, the well was stopped at 1,812 feet, just after encountering a very promising show of oil.

The area to be tested by this well is in the opinion of several geologists the most favourable in the country. Before drilling began, it was put on record that there were four geological horizons at which petroleum might be expected to occur, and the depths to these were estimated roughly at 1,500, 1,800, 2,600, and 2,900 feet. The first definite show of oil below a slight trace at shallower depth, was met with at 1,490

feet, and the second at 1,810 feet, where a very waxy oil was struck in a hard calcareous sandstone. The yield was never greater than seven barrels per day. Had this well been continued, it is possible that the lower horizons might have given better results.

From the above brief accounts of the attempts to find petroleum in British Dominions and Dependencies, it is evident that the Empire has been fairly thoroughly prospected; with the exception of British North Borneo, New Guinea, and some parts of Canada, there seem to be very few chances of developing new oilfields in countries that are not already producing in quantity.

There has, unfortunately, been a certain amount of prospecting of countries already condemned, and it may be that such unnecessary and useless work cannot altogether be prevented in the future, but in any case it is better that all possible chances should be considered rather than prematurely discarded.

The outlook for a sufficient supply of free oil from Empire sources is undoubtedly gloomy; it thus becomes necessary to give earnest attention to all other sources within the Imperial domains from which supplies of liquid fuels can be obtained.

C.—AREAS CONTAINING RETORTABLE MATERIAL

In a world in which the demand for petroleum products is steadily and continually increasing, while the supply is being maintained with difficulty, it is natural that the search for and study of alternative sources of liquid fuels are being prosecuted with vigour, though it is only recently that the necessity of utilising every resource has become apparent.

Up till the present the discovery of new oilfields and the deeper drilling in old-established fields have sufficed to meet requirements, and for some years to come there is no fear of a serious shortage. More efficient drilling and better precautions against waste may delay the evil day when the supply of free oil from well and storage will fail to meet the demand, but it may be expected that the cost of maintaining sufficient production will increase. This applies specially to areas where deeper drilling becomes necessary.

Any general increase in the world price of crude petroleum will obviously facilitate the production of oil by retorting or extraction methods, which can at present hardly compete with supplies of free oil, unless transport charges tip the scale in the favour of the former. It is, therefore, in countries that have to import petroleum that we find the most favourable fields for establishing a retorting industry.

The materials to be dealt with can be classified as follows:

(*a*) Oilshale and 'tar-sands.'

(*b*) Cannel coals (including torbanites).

(*c*) Lignites.

The treatment of bituminous coals will not be considered in this connection, as that subject falls to be discussed in another paper.

The British Empire, though containing very few oilfields, is fortunate in possessing large supplies of retortable material.

1. Great Britain

(*a*) *Oilshales.*—The oilshale industry is at present confined to Scotland, where it has existed since the sixties of last century. Oilshale is mined to the quantity of from 2,500,000 to 3,000,000 tons per annum, and a crude oil gallonage of upwards of 50,000,000 is extracted, while the yield of ammonium sulphate is approximately 50,000 tons. The richer shales are almost entirely worked out, and were it not for the ammonium sulphate, the industry would not be able to pay its way.

Recently conditions have been very unfavourable, and the works have been run at a loss. Two works have been closed and one mine shut down, but there is hope that a reorganization involving changes in retorting and refining methods might restore the industry to prosperity. If this can be accomplished, production of shale and of crude oil might be increased to some extent.

Of other oilshales in Britain, those of the Kimmeridge clay formation are alone worth considering, and no serious attempt has yet been made to mine and retort them on a large scale. In Dorsetshire there are thin seams interbedded with clays which could be mined cheaply and would yield approxi-

mately 40 gallons of oil per ton, some more and some less, but the crude oil is highly sulphurous, and thus expensive and wasteful to refine. The sulphur percentage is as much as 6. It has been estimated that in Dorsetshire there is enough shale to yield 897,000,000 gallons of crude oil, sufficient for a small local industry.

In Norfolk, oilshales of the same age have been exploited, but not successfully. The sulphur percentage in this case is from 6 to 8, and the oil yield is smaller than in Dorsetshire. The writer, after a careful examination of the evidence in 1917, was unable to find a seam of workable thickness, and further operations have only served to confirm this view.

The same shales occur in Lincolnshire and Yorkshire, but no workable proposition has been disclosed.

Shales of similar age are known in the island of Raasay, in the west of Scotland, but the yield of oil is small and its quality poor, being very sulphurous. These prospects are of no commercial importance.

(*b*) *Cannel Coals and Torbanites.*—These deposits were at one time made use of largely as gas coals, and in some cases as a source of oil. They afford very good prospects of establishing a small, but profitable, industry, when treated by modern methods.

In 1917, a fairly complete investigation of the country's resources in cannel coals was undertaken, with special reference to the total supplies available; at the same time, microscopical and chemical examinations of every seam were made, and retorting tests on a large scale were made to ascertain what quantities and what qualities of crude oil could be obtained. A mass of useful and important data was collected, but there has been no publication of the results.

In subsequent years much additional information has been obtained, and methods of treatment have been improved, with the result that it is found that the yield of oil can be increased by 10 per cent to 20 per cent, and at the same time the quality of the crude oil can be improved.

Nearly all the cannels of Britain are to some extent torbanitic, and some are really good torbanites; the yield of crude

oil and its quality improve according to the extent of the torbanitic development in the raw material.

There are not many collieries, however, where any use is made of the canneloid material. It is either left in the mine or thrown on to the waste heaps, and as the output from any one pit is seldom greater than 100 to 150 tons per day, the importance of this valuable source of oil has generally been overlooked. A comprehensive scheme was drafted for the utilization of cannels, and sites for works were actually considered, where it would be possible to assemble from a number of neighbouring collieries a total per day of approximately 1,000 tons. Seven or eight of such central retorting works could be established, without counting areas where supplies are not so plentiful and works on a smaller scale would be necessary. An alternative scheme is to erect small retorting units at each colliery that can produce sufficient cannel and transport the crude oil to central refineries. There should be no great difficulty, if all available supplies of good cannels were dealt with, in treating 2,500,000 to 3,000,000 tons per annum, a tonnage equal to that of oilshale mined in Scotland.

The yield of oil will naturally vary according to the nature of the material. Good torbanitic cannel will yield as much as 70 gallons per ton, and the poorest class of non-torbanitic cannel will give as little as 25 to 30 gallons, while the bulk will range between 40 and 50 gallons. An average of 40 gallons can be counted upon, when the newest and best methods of treatment are employed; this includes light spirit scrubbed from the effluent gases.

The crude oil made from a good cannel by an efficient low-temperature process is very different from the tars or tarry oils made from bituminous coal; it mixes in all proportions with petroleum without giving a precipitate of pitch, it contains good percentage of petrol and light oils, and after topping it makes a very good cracking stock. Petrol of high quality is made by cracking these oils, and the yield of petrol is high.

If all the available cannel coals were retorted for oil, and the crude oil cracked to make petrol, an annual production of at least 60,000,000 gallons of motor spirit would be obtained, and could be maintained for many years. Such an addition to the country's resources would have an appreciable effect

upon the balance of trade, a new and successful industry would be established, the coal mines would derive an extra profit, and employment would be available for a large number of men.

The rough estimates given above are all founded upon careful tests and actual experience, and err, if anything, upon the conservative side.

(*c*) *Lignites.*—There are no extensive lignite deposits in Britain, with the exception of those in the Tertiary basin of Bovey Tracey, in Devonshire, and possibly the Jurassic brown coals of Sutherlandshire. There are deposits of less importance in the Hampshire basin.

The value of a lignite as retortable material depends upon the stage of mineralization which it has reached. The lower seams in the Bovey Tracey area seem to be quite suitable for retorting, and are capable of yielding good percentage of the very valuable product 'montan wax.'

Recent experiments with new processes suggest that a profitable industry in mining and treating the better class of lignite could be established, but no very precise data as to the quantities available is to hand. It runs, however, to many millions of tons. It has been proved possible to make valuable oils from lignites, and the residues can be made use of locally in gas producers or under furnaces as source of power, or formed into briquettes.

No attempts on a large scale to utilize the lignites have been made, but in any scheme to develop the latent resources of the country they must not be forgotten.

To sum up, there are in Great Britain valuable sources from which oil can be obtained, but which are now being neglected. Of these the cannel coals and torbanites are the most important and the easiest to utilize, while the Dorsetshire oilshales and the Devonshire lignites are not negligible. Were all such materials made use of, the country would not be so dependent as it is at present upon import of petroleum and its products.

2. *Canada*

The Dominion of Canada is rich in various kinds of retortable materials which are at present neglected. The reason for this neglect is chiefly the proximity to the United States, whence cheap supplies of all grades of petroleum are imported. Another reason is that such attempts as have been made to produce oil by retorting processes have not been well advised, or have not followed the most efficient methods.

(*a*) *Oilshales.*—The greatest deposits of oilshales in Canada occur in New Brunswick in the Albert Series. These have been tested on a large scale in vertical retorts, and different seams have given yields varying between 27 and 48 gallons per ton, while ammonium sulphate up to as much as 77 lb. per ton has been produced. There are very large areas in which seams of oilshale, some rich, some poor, have been mapped, and where mining would be both simple and cheap, and in some localities shale could be won by opencast work for many years. No exact figures of the quantity available can be given, but estimates up to as much as 150 million tons have been put forward. In one case the figure of 47 million tons of oil has been calculated as available, but on what gallonage per ton of shale has not been made clear.

It is to be noted that low-temperature methods of retorting have not been employed, so it is probable that both the quantity and quality of the crude oil that could be produced might have to be increased.

The shale seams are well situated not far from the coast, and there is certainly a prospect of developing a successful oilshale industry.

Tar-sands, although not strictly speaking oilshale, may be considered under this heading. The great deposit of these exposed in the valley of the Athabaska and its tributaries in Alberta has been known for many years, and has been the subject of much research. The material is a sand fully impregnated with inspissated asphaltic oil, from 12 per cent to 20 per cent of the weight being hydrocarbons. The deposit has been proved over an area of, roughly speaking, 10,000 square miles; its thickness is seldom less than 100 feet, and

reaches as much as 200 feet. For all practical purposes the quantity may be said to be unlimited. Attempts to produce oil by drilling into this deposit have not been successful, though a small flow of heavy oil for a short period has occasionally been obtained.

At present much interest is being taken in this remarkable deposit, and work, both in the field and the laboratory, is being done to ascertain the best method of making use of the vast store of inspissated petroleum.

The methods suggested may be classified as direct and indirect. By direct methods is meant the extraction of oil as such in the field, tunnelling and mining after the Pechelbronn practice, and forcing steam down drilled wells. The latter method has recently been tried with success, though not over a lengthy period. A combination of the two methods might be successful under favourable conditions.

The indirect methods involve stripping the surface and mining the deposit in opencast workings by means of steam diggers. After it has been mined, either retorting or extraction by liquids must be resorted to. Retorting will give a yield up to 20 gallons per ton or possibly rather more; there will naturally be some cracking of the heavy petroleum. Extraction by hot water with an alkali or alkaline silicate in solution makes a good separation of the petroleum from the sand, and plant has been designed for this purpose. Extraction with kerosene has also been tried, but has proved expensive.

Whatever method or process be selected, it is obvious that it must be operated on a large scale. Worked like a low grade mining proposition, in which by dealing with a very large tonnage the costs per ton can be kept down to a minimum, there is every reason to believe that the tar-sand deposit can be exploited with commercial success. Once the crude oil has been obtained, it is possible to crack it by any efficient cracking process to make a good percentage of petrol. There is thus a good prospect of obtaining oil in ever-increasing quantity as the Athabaska country is opened up, and the supply can be maintained for hundreds of years. If, however, prolific oilfields should be developed in western Canada, heavy oil from the tar-sands will not be able to compete, and the exploitation of the tar-sands may have to be delayed.

(*b*) *Cannels and Torbanites.*—The only area in Canada in which canneloid material exists in quantity is Nova Scotia. In the coal basin near New Glasgow the presence of torbanites, locally called 'oilshales,' has been known for many years. The best known seam was worked extensively at one time, and was called 'stellarite,' owing to the manner in which it decrepitated and sparked in burning. This is due to the gels being of large size and usually isolated from each other; when heated sufficiently each gel caused a miniature explosion.

There are several seams of torbanite, including one or two of great richness, capable of yielding 70 gallons of oil per ton when retorted at low temperatures, and in addition to these there are very thick deposits of impure cannel, with a slight, but variable, torbanitic development. Some of the latter deposits could be worked by opencast methods for many years, but the yield of oil is small, not exceeding 38 gallons per ton, and falling as low as 30 gallons.

The coal basin has been mapped geologically, but is not fully explored yet, so it is not possible to give an accurate estimate of the quantity of retortable material that is available. One estimate puts it at 2,000 million tons, but this requires confirmation.

The area is well opened up by roads and railway, and is close to deep water at New Glasgow.

Under present conditions the richer seams could be mined and retorted at a profit, for the oil to be obtained, provided that a modern process is used, is of very good quality. The poorer seams might not pay for working unless the industry could be given some measure of protection, but if the price of free petroleum should rise, even the poorest seams will become a valuable asset.

Professor A. E. Flynn has made a special study of these torbanites, and his results are published in a brochure issued by the National Research Committee.

(*c*) *Lignites.*—In Alberta, Saskatchewan, and even Manitoba, there are great deposits of lignite of Cretaceous age, but they are not mined very extensively, except near Edmonton. Many of the seams are not suitable for retorting, but some of the deeper ones would probably give good results

with a newly invented process. Under present conditions—*i.e.*, with plentiful supplies of cheap petroleum imported from the United States, oil from lignites would not be able to compete in the open market. These deposits must, therefore, be considered as a reserve for the future: when it is possible to make use of them the quantity available is so great that a retorting industry once established could be maintained for generations.

3. *Australia*

(*b*) *Cannels and Torbanites.*—New South Wales is fortunate in possessing the richest torbanites in the world. These have been described frequently, but are often misnamed 'kerosene shales' or oil shales. Attempts to establish a mining and retorting industry have up to now proved unsuccessful, but have demonstrated the richness of the material. High mining costs and labour troubles are stated to have been the chief causes of failure, but perhaps a more serious cause has been the employment of old-fashioned methods of retorting that are not suitable for the treatment of such rich material. A yield of from 100 to 104 gallons per ton has been obtained from vertical retorts of the Scottish type, and the crude oil was of good quality. It is possible with a low-temperature process to get a yield of from 131 to 150 gallons per ton of a lighter and much more valuable oil. Even greater yields might be obtained from the best seams. The fields containing the torbanite seams are in the Triassic or Permian coal-measures, but much of the ground has not yet been fully prospected by boreholes, consequently the available tonnage cannot be estimated with accuracy. Nevertheless it has been calculated that sufficient torbanite has been proved to yield a total of 12,000,000 tons of oil, and this figure would require to be increased were a modern retorting process employed. The yield of ammonium sulphate from such torbanites is naturally small and can be neglected.

The great lignite basin of Morwell, some 50 or 60 miles from Melbourne, deserves consideration as a source of retortable material. The quantity of lignite available is enormous, and has never been fully estimated, but some idea of the quantity may be given by the fact that a boring 1,019 ft. in depth

passed through a thickness of over 700 ft. of lignite. The problem of mining such a deposit is no doubt difficult, but it might be solved by methods such as those employed in mining the diamondiferous pipes in South Africa.

The upper beds of this lignite are not of very good quality, but the lower seams, which have been affected by higher pressures, are apparently eminently suitable for retorting, and could be expected to yield from 40 to 50 gallons of oil per ton. There would be a considerable loss in refining the crude oil, but valuable by-products might be recovered. There is every reason to believe that with cheap mining a successful industry could be initiated.

In Tasmania an impure spore coal, known as 'tasmanite', is at present being exploited and retorted, the yield of oil being approximately 40 gallons per ton. The seams of tasmanite have been proved over a considerable area, and though no very precise figures are available, it has been calculated that there is sufficient material to yield 1,400,000 tons of oil. The industry of mining and retorting the tasmanite has good prospects of proving successful.

4. South Africa

(*b*) *Cannels and Torbanites.*—The only hope of developing an oil industry in South Africa is by mining and retorting the torbanite and cannel seams of the Transvaal. The torbanite seams are thin, but occur in coal seams, so that a working thickness can be mined. In the Ermelo and Wakkerstroom districts there has been a certain amount of careful prospecting done, though it would be premature to state that anything like the full tonnage available has been estimated. Much boring and development work will be required yet.

The deposits vary in quality as well as in thickness, and no serious attempt has yet been made to develop any area. Much of the material is very rich, yielding as much as 92 gallons per ton by a low-temperature process; laboratory or small-scale tests indicate that higher yields are possible, but for practical purposes only large-scale retorting tests are to be regarded.

The mining, which will be at shallow depth, or from adits, will be very inexpensive, and the quality of the oil that has been obtained from these torbanites is excellent, containing good percentages of petrol, kerosene and solid paraffin.

The tonnage of torbanite available is somewhat doubtful as yet, but in two districts alone it may be put provisionally at approximately 30,000,000 tons.

Besides the torbanites, there are workable cannel seams with a slight torbanitic development, capable of yielding up to 40 gallons of crude oil per ton. These have not been prospected nor developed in any way, but show workable thicknesses where they have been opened at outcrop.

Summing up the prospects, it can be stated that there is sufficient material of sufficiently good quality to base a successful retorting industry upon. The costs of freight of imported oil to South Africa and its transport up-country give such an advantage to a local industry that it could hardly fail to be successful.

Except for occurrences of oil shales in Burma, New Zealand, Newfoundland and one or two other places, all of which must at present be reckoned as doubtful prospects, the above mentioned fields complete the list of prospective sources of liquid fuel in the Empire. It follows to make some attempt to estimate what would be the effect of developing them with the end in view of making the Empire self-supporting in supplies of oil.

Firstly, it is evident that the supply of retortable material is very large.

Secondly, it is obvious that it is to retortable material rather than to free oil that we must look if sufficient supplies for Imperial needs are to be forthcoming.

Thirdly, it is obvious that the development of fields of retortable material cannot be commenced immediately except upon a comparatively small scale; much careful prospecting and boring remains to be done in several of the areas where the greatest resources occur, and it will take many years to build up retorting industries of sufficient size and importance.

The Empire's imports of liquid fuels are, roughly speaking, 3,050,000,000 gallons, made up as follows:

Canada	670	million gallons
Australia	165	" "
South Africa	36	" "
New Zealand	50	" "
Great Britain	1,600	" "
Other Colonies and Dependencies	515	" "

This excludes all solid products such as asphalt and paraffin wax. A proportion, but not a large one, of the imports are from British sources, but we may consider the total of 3,000,000,000 gallons as roughly speaking the needs of the Empire, a figure which is liable to increase, and may have increased considerably since the latest statistics have been published.

Put into tons, with a due allowance for the specific gravity of the oils, this comes to upwards of 11,000,000 tons of petroleum products required for the Empire in each year, and in future years the demand is sure to increase.

It has been seen above that a total of 3,000,000 tons of free oil from Empire sources is all that can be counted upon; this leaves 8,000,000 tons to be supplied from other sources.

Persia, the United States and other foreign countries at present supply the deficiency. Can this deficiency be supplied under the most favourable circumstances from Imperial sources?

For Great Britain the answer is quite simple; under the very best conditions, with cannels, torbanites, oilshales and lignites all being regularly worked and retorted, the production of oil will be only one-eighth to one-sixth of requirements.

Canada is in a better position; with the oilshales of New Brunswick and the torbanites of Nova Scotia developed up to an annual output of 1,000,000 tons each, and the tar-sands of Athabaska developed at the rate of 2,000,000 tons, one-fifth of the requirements of the country could be satisfied, while if the prospective oilfields of Alberta prove successful, a further large supply would be forthcoming. If the retorting material were worked on a really large scale, the country might be made practically self-supporting.

South Africa could supply its own needs by working and retorting 500,000 tons of torbanite and cannel, and could maintain the necessary output for many years.

Australia, from its torbanite, tasmanite and lignite, could become self-supporting, though the output of these materials would require to be worked up to something of the nature of 3,000,000 tons per annum.

Trinidad could supply the West Indies, British Guiana, and British Honduras, and stilll have a good surplus for export to other countries.

Burma, Assam, and the Punjaub between them should be able nearly to supply India.

New Zealand will probably always have to depend on imports, and the same may be said of Newfoundland and the East and West African Colonies, and there remain many smaller colonies and dependencies whose needs must be supplied.

Considering the question as a whole, it appears practically impossible for the Empire ever to be entirely self-supporting from the sources dealt with above, unless work on a gigantic scale were undertaken, but with the help of Persia, which produces some 5,000,000 tons of oil per annum, it should not be difficult to keep every dominion, colony and dependency supplied, and retain in storage a sufficient quantity of petroleum products for emergencies.

It is an ideal to be worked for, even although it may take many years before such a desirable position is within reach.

PETROLEUM REFINING FACILITIES WITHIN THE BRITISH EMPIRE

By James McConnell Sanders (*Member, Inst. Petr. Tech.*)

(Jasper, Alta, Meeting, September 19th, 1927)

A study of the British Empire's resources for the production of crude petroleum must be incomplete unless at the same time its available or potential facilities for refining it are included in the picture.

While it is unfortunately true that it depends upon foreign countries for the greater part of its petroleum supplies, it is equally unfortunate that so much of the crude oil production it controls politically or financially has to be worked up under alien flags, and is subject at all times to interruption from conditions outside Imperial control.

The establishment of refineries in Great Britain itself would appear to be a political rather than an economic necessity, for many arguments could be found for placing the manufacturing plant as close as possible to the source of raw material which feeds it. When markets for the reception of the finished products are available in close proximity both to oil-fields and refineries such arguments are considerably strengthened.

The ideal conditions exist in the United States, where fields, refineries and markets are linked together with a comprehensive system of pipelines and other means of transport.

The British Empire, having no source of crude oil within its frontiers sufficient to supply its necessities, must perforce substitute for pipeline linkages the mobile elements of its mercantile marine, and this in itself provides an argument for establishing installations for the manufacture of fuel oil, whether for aircraft or seacraft, at the home bases of its ships.

Of equally vital importance is the supply of lubricating oils, without which all the machinery in the Empire would quickly come to a standstill.

The object of the present study is to briefly survey the position of the Empire if it were called upon to not only produce but also refine all the petroleum products it needs.

At the present time importations into British Dominions amount to about ten million tons annually of petroleum or its derivatives. Of these, nearly one half is designated 'crude oil,' and of this crude about 4,650,000 tons goes to Great Britain and Canada, the remainder being absorbed by Australia, New Zealand, Egypt, Ceylon, Cyprus, St. Vincent, British Guiana and Newfoundland.

Canada and Great Britain divide this imported crude almost equally, but from the point of view of refining facilities, Canada's quota of 2,328,667 tons per annum must be increased by its own production of 45,465 tons, less its exports of 27,147 tons.

The position is summarized in Table I, which shows the amount of crude oil presumed to have been refined during 1925 by each country in the Empire which is known to possess refineries.

Table 1

Crude Petroleum Imports and Exports, for countries possessing Refineries

(In tons per annum)

	Great Britain	Canada	Trinidad	India	Sarawak	Egypt	Australia
Crude—							
Production.....	nil	45,465	637,423	1,193,779	603,270	176,764	nil
Imp't'd.	2,322,783	2,328,669	nil	nil	nil	4,187	170,191
	2,322,783	2,374,134	637,423	1,193,779	603,270	180,951	170,191
Exported	301	27,147	42,910	19,112	151,908	nil	nil
Refined..	2,322,482	2,346,987	594,513	1,174,667	451,362	180,951	170,191
Equivalent to barrels daily....	54,187	54,671	13,867	27,405	10,528	4,221	3,969

From this table it may be deduced as a first approximation that the countries mentioned are capable of refining at least 170,000 barrels of crude oil daily, or as much as four large installations in the United States could handle easily.

According to one authority(1) there were 509 refineries in existence in the United States on January 1st, 1926, 352 of which were operating with a daily capacity of 2,560,000 barrels, 157 were shut down (290,000 barrels), and two were under construction (5,000 barrels).

According to the *Board of Trade Journal* the quantity of crude petroleum refined in Great Britain during 1926 was 539 million gallons, or about 123,000 tons less than in 1925, so that for the purpose of gauging the prospective refining capacity of Great Britain itself the figures for the latter year would appear to be more suitable.

As regards the other countries in the Empire, the complete statistics for 1926 are not yet available, so that those for 1925 have been also utilized in the following discussion.

Table II is taken from the Board of Trade compilation above referred to, and shows the comparative yields of liquid products obtained from foreign crudes, refined in Great Britain.

Table II

Products obtained from Crude Oil refined in Great Britain during 1926

(In million gallons)

Product	1926	1925
Throughput:		
Petroleum	576.42	598.09
Shale oil	39.86	50.21
Output:—		
Motor spirit	173.34	178.73
Other spirit	14.25	7.59
Kerosene	63.63	75.96
Gas oil	28.79	29.19
Lubricating oil	8.15	6.33
Fuel oil	266.16	307.81
Other liquid products	0.13	0.01
Total liquid products	554.45	605.62

(1) *The Oil Trade*, XVII, 3, 51.

Considering only those products which needed refining in the literal sense, the comparative proportions for the two years mentioned works out as follows:

	1926 Per cent	1925 Per cent
Motor spirit	31.2	29.5
Other spirit	2.6	1.3
Kerosene	11.4	12.5
Lubricating oil	1.5	1.0

From which it is observed that the proportion of motor spirit increased in 1926 to about the same extent as that of kerosene decreased, while that of other varieties of spirit was doubled.

Official statistics covering the production of crude oil convey very little information regarding the refining possibilities of the raw material, or its content of useful components. This in itself makes it difficult to correlate refining facilities with the oil to be refined, just as difficult, in fact, as it would be to define the size of harbour required to accommodate a given tonnage in 'ships'.

Similar difficulties exist in attempting to define the capacity of a refinery, although it is common practice to speak of an installation as having a daily or monthly capacity of so many barrels or tons of crude oil.

The composition of crude petroleums and the extent to which they may be refined, either by distillation or by chemical and physical treatment, are so variable that nothing short of a separate study of each individual oil with its available plant and possible market would allow an even approximate estimate to be made of the relation between them.

Some kind of artificial basis is therefore required in order to reduce statistics to a common measure of comparison.

As regards 'capacity' of a refinery, the writer has adopted as a conventional unit the number of barrels of crude oil which can be distilled daily with an offtake of 20 per cent by volume.

This is really a measure of distillate capacity, although in what follows it will be spoken of in terms of throughput.

The possession of the necessary equipment for re-running crude distillates, and of chemically treating them, as well as the inclusion of auxiliary plant for extracting and refining paraffin wax, filtering lubricating oils, etc., is taken into account in the following subdivision of the subject:

Complete Refineries.—Include those installations which in addition to topping plants, possess steam stills, re-run stills and either asphalt stills or wax plants or both. They possess all the necessary equipment for chemical treatment of the crude distillates to the extent necessary from the nature of the crude they are handling. They may or may not possess equipment for making and filling tin cans and cases, barrels, drums, etc., or plant for manufacturing sulphuric acid or other chemical reagents.

Semi-complete Refineries.—Include establishments which have topping and redistillation units and treating plants for light fractions only. Their capacity is measured in terms of crude oil, although they may actually be engaged in refining a distillate or residuum derived from another refinery.

Cracking Plants.—Although these are in some cases part of the equipment of a complete or semi-complete refinery, they are considered as separate establishments, and their capacity is measured in barrels of charging stock throughput per day.

When separate installations are considered these are presumed to include the necessary plant for treating the cracked products.

Oil Treating Plants.—In this category are included all small installations engaged in making special products, such as blending of lubricating oils, compounding greases, etc.; no attempt has been made to estimate the capacity of such plants since no common basis is available.

With the above as a basis, Table III has been prepared showing approximately the refining capacity of installations within the British Empire, and from this it is evident that the latter is not yet in a position to refine the products which it now receives from other countries.

Table III

Petroleum Refineries Operating within the British Empire

Country	No.	Complete. Capacity bbls. daily	No.	Semi-complete. Capacity bbls. daily	No.	Cracking plants. Capacity, bbls. daily	Oil treating plants	Total No.	Refineries capacity, bbls. daily
Gt.Britain	1	30,000	13*	25,000	5	11,500	37	56	66,500
Canada....	4	72,000	12	30,000	2	3,200	9	27	105,200†
India.....	2	50,000	2	1,200	2	3,500	(a)	6	54,700
Trinidad..	–	—	5	25,000	1	1,600	(a)	6	26,600
Australia.	–	—	2	3,000	1	750	(a)	3	3,750
Egypt....	–	—	3	15,500	–	—	(a)	3	15,500
Sarawak..	–	—	1	19,500	–	—	(a)	1	19,500
Total...	7	152,000	38	119,200	11	20,550	46	102	291,700

*Includes shale oil refineries. †There are also five natural gasoline plants.
(a) Information not available.

In order to estimate what facilities would be necessary in order to make the Empire independent of foreign refineries it is necessary to know the actual consumption within its borders of products which have needed refining.

As regards Great Britain the *Board of Trade Journal* gives the summary shown in Table IV for the year 1926, but in the case of other countries within the Empire, the difference between imports and exports does not provide the necessary data for arriving at its consumption, because in those countries which are at present producing and refining, a part of the output is consumed locally and does not appear in the officially published statistics.

It is proposed therefore to arrive at the true consumption by indirect methods.

In the case of those countries which are producing crude and refining it, a knowledge of the crude handled in each individual case is considered. Table I shows the amount of crude refined; Table V shows the average yields of products from

those crude oils which are obtained in commercial quantities. After making certain adjustments to cover conditions known to exist, the quantity of a product which could be obtained from a particular crude, less the amount exported plus the amount imported, represents the quantity consumed in the country in question. This is shown in Table VI.

Table IV(1)

Products Retained for Consumption in Great Britain and Northern Ireland in 1926.

	Motor spirit	Other spirit	Kero-sene	Gas oil	Lubri-cating oil	Fuel oil
Imports (other than for refining)	561.88	2.92	173.42	117.04	91.66	398.91
Re-exports	18.43	0.04	7.48	1.46	2.53†	1.61*
Retained imports	543.45	2.88	165.94	115.58	†	397.30.
Home production from imported and native petroleum and from shale	173.34	14.25	63.63	28.79	8.15†	266.16
Exports	39.95	0.06	25.96	2.51	7.64†	51.10*
Retained home production	133.39	14.19	37.67	26.28	†	215.06
Total retained	676.84	17.08	203.61	141.86	89.64	359.16*
Shipped for the use of steamers engaged in foreign trade	—	—	—	—	—	253.20
Total retained in 1925	486.96	13.84	164.84	97.56	82.45	302.25*
Bunkers in 1925	—	—	—	—	—	252.18

*Excluding fuel oil shipped for the use of steamers engaged in foreign trade.

†It will be understood that the figures of output of lubricating oil relate to production by refiners of crude petroleum and shale oil and do not include the manufacture of lubricating oils by merely blending or further refining imported lubricants. It is not possible to distinguish the exports of such blends, etc., and therefore not possible to state the retained home production.

(1) *Oil News*, XXII, 749, 368.

Table V.

Yields of Commercial Products from crudes obtainable in commercial quantities

Country	Gasoline	Kerosene	Gas oil	Lub. oils	Asphalt fuel loss	Wax
	%	%	%	%	%	%
Canada.....	11.8	52.4	16.2	12.3	4.8	1.5
Burmah.....	28.0	35.0	6.0	13.0	8.0	10.0
Assam.....	16.8	30.2	3.4	10.8	19.3	19.5
Trinidad (a)	32.6	28.4	16.0	19.6	1.2	2.2
" (b)	40.0	15.0	6.0	15.0	22.7	1.3
" (c)	8.0	2.0	20.0	12.0	52.0	—
Sarawak.....	14.0	8.0	25.0	10.0	43.0	—
Egypt.....	8.0	15.0	43.0	—	29.0	5.0

(a) Paraffin base. (b) Mixed base. (c) Asphaltic base.

Table VI

Estimated Consumption of Products which would have Required Chemical Treatment

(In long tons per annum)

	Motor spirit	Kerosene	Lub. oils	Wax
Countries producing petroleum:				
Canada.....	698,683	201,446	45,236	35,645
Trinidad.....	56,316	98,449	641	—
India.....	20,537	612,731	263,397	141,829
Sarawak.....	74,074	—	45,455	—
Egypt.....	33,788	24,627	1,133	—
All other countries..	1,667,311	739,891	398,728	63,052
Total.....	2,550,709	1,677,144	754,590	240,526

This calculation has been made with the aid of official statistics published for the year 1925, the complete data for 1926 not being at present available.

For the purpose of subsequent calculations only those products which required chemically treating are included, but it is necessary to point out that with the exception of Canadian oils which are high in sulphur content, the oils at present found within the British Empire are remarkable in requiring very little chemical treatment.

The table for consumption, however, shows products which include those derived from foreign crudes, and which in many cases needed more drastic treatment in refining them than would have been the case if they had been entirely derived from Empire crudes.

It is worth while considering that in the future such easily refined crudes may not be available, and that even if sources of crude supply become available which can supply the Empire's requirements entirely, it is more than likely that they may be of a refractory nature, highly sulphurous and asphaltic and require considerable chemical treatment.

If the tar-sands of Alberta, or the large deposits of shale in other countries ever come to represent the main source of the Empire's petroleum requirements, the refining of the latter will not be nearly so easy as is the case with, for instance, the crude from Burma.

Again, the present trend of refinery activity is in the direction of utilizing more and more the cracking of heavier oils for the production of motor spirit, and cracked products require more extensive refining than straight-run products.

Having in mind the above it has been considered worth while investigating the probable requirements of the Empire in chemical reagents, assuming that the consumption of products shown in Table VI represents the average necessities of its consumers.

For this purpose a conventional treatment with acid and alkali with alkaline plumbite for motor spirit and kerosene, is taken as a basis, although naturally this method may be eventually substituted by others in certain cases.

The hypochlorite process, which has been successfully applied with oils of the Persian type may be found applicable over a much wider range of oils, and would reduce the sulphuric

acid requirements of the Empire. Again, it is not unlikely that existing market specifications as regards colour and sulphur content of many products may be eventually relaxed and make the task of the refiner less onerous.

Table VII has been prepared so as to represent the probable amount of chemical reagents necessary to treat the Empire's requirements in refined products starting from the quantities of finished products shown in Table VI, and making the necessary allowances for treating losses.

Table VII.

Estimated Chemical Requirements for Refining the Empire's Requirements of Petroleum Products

(All quantities in long tons per annum)

Products (untreated)	Quantity	H_2SO_4 = Sulphur = Pyrites			Caustic soda	Litharge	Fuller's earth or bauxite
Motor spirit.	2,600,000	23,214	8,148	16,296	2,785	409	—
Kerosene....	1,700,000	29,219	10,256	20,512	2,276	380	—
Lub. oils.....	795,000	24,844	8,720	17,440	2,484	—	79,500
Paraffin wax.	245,000	7,656	2,687	5,374	766	—	6,125
Totals.....	.....	84,933	29,811	59,622	8,311	789	85,625

As regards the Empire's ability to supply these requirements the following outlines very briefly the present position:

Sulphuric acid, Sulphur, and Pyrites.—According to Sir Max Muspratt(1), the sulphuric acid trade in Great Britain is at present in a state of comparative torpidity. In 1915, before the real war expansion, the production in this country was 1,083,000 tons expressed as 100 per cent acid, and the capacity 1,200,000 tons. In 1925 the production was 848,000 tons, the capacity 1,400,000 tons: a drop of 235,000 tons in production, a gain of 200,000 tons in capacity.

(1) *Journ. Soc. Chem. Ind.*, XLV, 250, 1926.
The Petroleum Register, 1926.
The Oil and Petroleum Manual, 1926.
The Imperial Mineral Resources Bureau, 1926.

The same author points out the great alteration which has taken place in the proportions of acid made from imported and domestic pyrites, from spent oxide, from brimstone and from zinc and copper smelter fumes. The comparative figures are as follows:

	1914	1925
Proportion of total acid made from:	%	%
Imported pyrites	88.45	47.0
Domestic pyrites	0.5	—
Brimstone	0.3	23.5
Spent oxide	10.6	24.0
Zinc and copper fumes	0.15	5.5
	100.00	100.00

The increase in the proportion of acid made from spent oxide is interesting, since this material is the only raw material available in England. It is derived from the gas works industries in the process of desulphurising coal-gas, and it is possible that some of its contained sulphur may come from petroleum gas oil which has been used for enriching the latter.

The greater part of the world's supply of sulphur is derived from the United States, Italy, and Japan. Although deposits exist in Canada, the Dominion imports the greater part of its requirements from the United States. India also imports sulphur and so does Australia, although both these countries possess deposits and have experimented with the utilization of smelter fumes. As regards the latter method of obtaining sulphur for acid manufacture, it is reported that a new factory at Coniston, Ontario, is utilizing escaping gases from nickel smelting works to manufacture 25,000 tons per annum of sulphuric acid.

New Zealand exports a small quantity of sulphur but the supply is diminishing, and she imports considerably more than she produces.

The position in 1925 according to official statistics is as follows:

The British Empire:		
Produced.....	73,769 tons	(from spent oxide)
Exported.....	303 "	
	73,466	
Imported.....	345,046 "	(excluding flowers of sulphur)
	418,512 "	

The United States is the greatest producer of sulphur and in 1925 although the output increased by nearly 16 per cent, the demand was so great that stocks had to be reduced by 450,000 tons.

The exhaustion of mines in Louisiana resulted in the Texas deposits becoming the chief source of supply, and altogether the indications are that a shortage of brimstone is likely at no very distant date, in which case the Empire may be dependent upon other sources of supply in order to meet its acid requirements.

In this connection it may be worth while pointing out the sulphurous crude oils and bitumens themselves as future providers of the element. A 30,000-bbl. refinery, handling a crude oil with a sulphur content of 3.5 per cent takes into its stills daily 140 tons of sulphur. If it burnt its own heavy residuum as fuel it would eject about 14 tons of sulphur as sulphur dioxide from its chimneys, and about 7 tons as hydrogen sulphide from its uncondensed still gases. For the refining of its products it will need somewhere about the equivalent of 14 tons of sulphur as sulphuric acid per day, and it will utilize this in extracting only 2 tons of sulphur from its products.

We have then the anomalous position of a commercial establishment having to purchase 14 tons of sulphur as acid in order to extract 2 tons of the same substance from its product, while at the same time sending 21 tons of the same substance into the air from its chimneys!

In the case of petroleum refineries manufacturing their own acid, the contact process is preferred, although in some cases chamber plants have been erected in localities within easy reach of nitrate supplies. The contact process, when using brimstone, is easier to handle and occupies less space than the chamber plant, while unlike the latter there is no accumulation of by-product to dispose of. On the other

hand, brimstone is almost a necessity for the successful running of a contact plant under refinery conditions unless an elaborate dearsenicating system is installed and some outlet exists for disposing of the burnt mineral.

While Great Britain depends almost entirely upon imports for its supplies of pyrites, important deposits exist in South Africa, Canada, Newfoundland, and Cyprus, although they are not exploited to their full capacity. Australia possesses a small amount, and also utilizes the fumes from the roasting of lead-zinc ores, but the amount of acid produced falls short of its requirements. The Empire's position in 1925 was as follows:

Production	195,000
Exports	179,121
	15,879
Exports	275,322
	291,201

Fuller's earth and Bauxite.—Very little information is available as regards the true production within the Empire of fuller's earth.

In 1924 India produced 4,078 tons as against 27,696 in 1923, while Australia produced 50 tons only in both years. Undoubtedly, the United States is the main source of supply and in 1925 it produced 184,441 tons. English earth, although serviceable in the treatment of vegetable oils, has not found much favour with refiners of petroleum products, and although a large number of bleaching earths are prepared in foreign countries, by special treatment, the Empire has done comparatively little in the way of providing a substitute for the natural Floridin.

Bauxite is used quite extensively but does not work successfully with all types of oil. The British Empire produces about 16 per cent of the world's supply, which in 1925 totalled 1,290,000 tons, the Empire's position being approximately as follows:

	Tons.	Tons.
Production:		
Northern Ireland	5,040	
British Guiana	194,339	
India	11,000	
Total		210,379
Exports:		
British Guiana		174,999
		35,380
Imports:		
Great Britain		74,850
		110,230

Caustic soda and Litharge.—These two requirements of the refining industries do not require discussion, since for the amounts needed the British Empire's resources would be more than adequate.

Other refinery supplies.—It may be of interest to mention a few of the manufacturing supplies which, while not peculiar to the petroleum industry, are nevertheless to be catered for when considering the possibility of the British Empire having to stand on its own legs with regard to such material. No attempt has been made to review its position from a quantitative viewpoint vis-à-vis its competitors in the field of endeavour, but taken in conjunction with the estimate already made of its requirements in refined products, the estimates herewith presented may be of interest.

Asphalt barrels.—In order to meet the Empire's annual requirements in barrelled asphalt about 1,885,440 sets of cooperage would be required. The United States and Canada are the main sources of supply, and it is estimated that for average classes of timber it would require 1,500,000 cubic feet of wood to supply this quantity.

Tin cans and Solder.—If half the motor spirit and kerosene consumed within the Empire and all the lubricating oil, were delivered to the consumer in 4 gallon cans, there would be needed 184,000,000 cans per annum, which would require at least 2,464 tons of solder in their manufacture. It is probable that the Empire is self-supporting as regards the steel, lead and tin required.

Wax plant supplies.—The annual consumption of wax would, under normal working conditions, require the Empire's wax plants to be supplied with 741 tons of calcium chloride and 328 tons of anhydrous ammonia, in order to make good the usual wastage. Cotton filter blankets represent a special class of manufacture which was formerly manufactured principally in the United States, but British enterprise has successfully overcome the technical difficulties and now blankets in every way equal to the imported article can be turned out by Imperial looms.

Refinery constructional material and plant.—This is a very comprehensive subject which could scarcely be treated adequately within the limits of the present article. In a general sense it would appear that as regards the greater part of the steel work required in refinery installations the British Empire does not need to go outside its own frontiers to meet its requirements, either in raw material or finished component. Not many years ago storage tanks of the size and type required by the petroleum industry were largely supplied by other countries. The same may be said of stills, pipe-line material, filter-presses and other special appliances. The position is very different to-day, however, and a large number of firms within the Empire are in a position to cater for the requirements of even a very large refinery, and are probably only limited by geographical considerations from becoming serious competitors of the former alien specialists.

Outside of those materials which are common to any large engineering undertaking, there are few which the petroleum industry looks upon as indispensable, and upon which any doubt could be entertained as regards the ability of the Empire to supply it.

Asbestos is needed as an important component of heat resistant packing material, for which no efficient substitute could be found. It is produced by Southern Rhodesia, Canada, Cyprus, India, Australia, and the Union of South Africa, the position in 1925 being approximately as follows:

Production	292,000
Exports	280,883
	11,117
Imports	59,224
	70,341

From this it would appear that the Empire could meet its requirements without going outside.

Fireclay, diatomaceous earth and similar material could probably be supplied from Empire resources as far as the petroleum industry is concerned although at present it imports rather more of the latter material than it produces. On the other hand, it could probably be substituted by other material as regards its use as an insulator. The position as regards platinum for contact sulphuric acid plants is a little difficult to define. The Empire produced 4,000 troy ounces in 1925, and imported about 93,000 ounces while exporting 8,050 ounces. But platinum is not a material which is consumed in the sense of being destroyed, and therefore the position of the Empire for supplying prospective acid plants, could only be reviewed with a knowledge of its available stocks, and information regarding this is presently unavailable.

Technical Staff.—As a comparatively recent entrant into the arena of petrolific competition, the British Empire has had to depend very largely upon the services of alien technologists, in the past decade, in order to develop its own resources. While the Scottish shale industry may be regarded as the parent of the great petroleum industry which flourished on the other side of the Atlantic, it is undoubtedly due to the exceptional opportunities for development *in situ* that the descendants of that parent have for long been able to act as technological mentors to their cousins on this side.

In everything except on the purely engineering side of the refining industry, Great Britain and the Empire generally has for many years been content to obtain technical assistance from other countries which had been engaged in petroleum refining. The advent of the Great War revealed the weakness of the Empire in this respect, and since the armistice the measures taken to correct it have steadily developed. For

this result, the enterprise, foresight and generosity of the great petroleum companies which are operating within the scope of the Empire's political or financial control, are largely responsible. But the Government itself has long been aware of the necessity for providing from within its frontiers the technical assistance needful for not only exploring its potential resources but also for exploiting them in the national service.

At several educational centres special courses of instruction are provided for training petroleum technologists, whether on the geological, engineering or refining side of the industry, while opportunities are constantly provided for young men to learn the practical side of refining in installations within their reach.

The outlook for the future is therefore very hopeful, and against such time as may elapse before the Empire is possessed of sufficient crude supplies to guarantee its independence, it may confidently rest in the assurance that it will have all the necessary facilities both in 'men and metal' to turn those supplies to useful purpose.

For much valuable assistance in compiling the information contained in the above, the author is indebted, and desires to record his gratitude, to the following:

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PETROLEUM AND NATURAL GAS IN THE DOMINION OF CANADA†

Preface

By John Ness (*Member, C. Inst. M. & M.*)*

(Jasper, Alta., Meeting, September 19th, 1927)

Canada, although one of the world's earliest oil-producing countries, has suffered an almost total eclipse, as far as petroleum is concerned, since the dawn of the 20th century.

The birth and infant growth of the petroleum industry was coincident in Canada and the Republic to the south, but while development in the United States spread with the rapidity of a prairie fire and resulted in the bringing-in of pool after pool, and field upon field, until the United States became the world's greatest oil-producing country, the discoveries in Canada were confined to a few relatively small fields in southwestern Ontario.

As the production of petroleum became general in other countries, apparently more lavishly endowed by Nature than our own, so did Canada's importance as a factor in the problem of the world supply diminish. Concurrently, through the application of petroleum to the modern channels of light, heat, power, and lubrication, our consumption of petroleum and its derivatives increased by leaps and bounds, and, as a consequence, we have become one of the large oil-importing countries.

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†Includes the following papers:
Oil and Gas Fields of Ontario, by R. B. Harkness.
Oil and Gas Prospects of the Great Plains of Western Canada, by G. S. Hume.
Oil and Gas Development in the Foothills Belt of Alberta and British Columbia, by O. B. Hopkins.
Oil Prospects of British Columbia, by G. S. Hume.
Bituminous Sands of Northern Alberta, by S. C. Ells.
The Mackenzie River Area, by G. S. Hume.
Natural Gas in Canada, by R. T. Elworthy.
Petroleum and its Products in Canada, by S. J. Cook.

*Geological Dept., International Petroleum Company, Limited.

We go far afield for our supplies. Pipelines connect us with the mid-continent fields in the United States; tank cars, in never-ending procession, convey the product of Montana and Wyoming to the western refining centres; the waters of two oceans are ploughed by ships carrying Gulf Coast and South American crudes to our ports; and, by such means, we import some fifteen or sixteen million barrels of crude oil annually.

Petroleum refining is one of Canada's important industries, but, of the tremendous amount of crude handled at the many up-to-date plants, only some 2 per cent is of domestic origin. With such conditions obtaining, it is not surprising that strenuous efforts have been, and are being, directed towards the discovery of new sources of supply within the Dominion.

In these researches, the western provinces have held the centre of the stage during recent years, owing to the fact that they cover regions known to be underlain by rocks of bituminous antecedent, and, in certain defined areas, suitable structure for the concentration of petroleum reserves is apparent.

The results of this campaign have been sufficient to encourage the hope that production on a commercial scale is not out-with the realm of possibility, and operators, whether individuals or corporations, are continuing their prospective drilling with renewed hope in consideration of the more recent developments.

In the following pages we present a critical review of the Dominion's proved, probable, and possible oil-fields, necessarily brief, but nevertheless of considerable weight, as expressing the view-point of men whose knowledge of the subject is based on painstaking work in the field.

Due to the co-operation of various Departments of the Federal and Provincial Governments, and of Imperial Oil, Ltd., which we deeply appreciate and heartily acknowledge, we are enabled to submit this impartial and authoritative survey, with the hope that it may prove of assistance to anyone who delves, metaphorically or otherwise, into Canada's petroleum resources.

THE OIL AND GAS FIELDS OF ONTARIO*

By R. B. Harkness (*Member, C. Inst. M. & M.*)**

Introduction

The important gas and oil fields of Ontario are to be found bordering on lake Erie, and in the county of Lambton and in the southern halves of Middlesex and Brant counties. A small gas pool in Amabel township, Bruce county, has been producing gas for twenty-seven years, and a few non-commercial gas and oil wells are found along the south shore of Georgian bay and the most easterly portion of Manitoulin island. These range in depth from 400 feet to 3,600 feet, and the rocks in which they occur range from Devonian to Lower Ordovician or probably Cambrian in age (See Figure 1).

The portion of Ontario under discussion has been a buffer in the disturbances that formed the Appalachian and Michigan basins. It lies on the edge of the great Laurentian shield, and was only slightly affected by these movements. However, the subsidence of these two basins is undoubtedly responsible for the geographical features of southwestern Ontario. Where the rocks are exposed, the dip is so gradual as to be scarcely noticeable; but it will be found that southwestern Ontario forms the rim of both basins mentioned, with dips towards their centres averaging about twenty feet to the mile. The southwest peninsula of Ontario also forms a prolongation of the Cincinnati anticline, which plunges toward a central point in Kent county and forms a saddle between the Michigan and Appalachian basins at that point, the total depression of which is slightly over 2,000 feet. It is in this area that our best oil and gas fields in all formations have been found to date. The Cincinnati anticline is very pronounced in the State of Ohio and in Essex and Kent counties, Ontario; but it flattens out in a northeasterly direction and is not recognizable as an anticline east of Middlesex county.

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**Natural Gas Commissioner for the Province of Ontario.

GEOLOGICAL SEQUENCE

The accompanying Table (insert) gives the geological column for that portion of Ontario where most of the oil and gas fields are situated.

EARLY HISTORY

The original discovery of oil in Canada was at the present village of Oil Springs, Lambton county, Ontario, along Black creek, where a seepage of oil had been observed for many years. As early as 1858 wells were dug to the gravel bed on top of the rock, a depth of from 40 to 60 feet, and a heavy oil was recovered which was used, without any treatment, as a lubricant, and commanded a high price; some of this oil is still recovered after spring freshets. The first well was drilled at Oil Springs in 1861, probably in the month of February. This date is given by Winchell (1) as February 19th, 1862, but it is evident from Sir William Logan's report on the *Geology of Canada* (1863), page 786, that the well was drilled at least one year earlier, and in the *Report of the Royal Commission on Mineral Resources in Ontario* (1890), pages 158 and 159, J. H. Fairbanks states quite clearly in his evidence that the date is 1861.

These early wells were drilled by suspending the drilling tools on the end of a springpole. The end of the pole was 'kicked' down (2), allowing the tools to drop and strike a blow at the bottom of the well. It is stated that it took three months to drill one of these shallow wells; but this method of drilling was soon replaced by the American system, which, in its essentials, has not varied much to this day. Some drillers used jointed poles, rather than a cable, on account of the time saved when 'fishing' was necessary. The use of pole tools has now passed into history, with the possible exception of certain foreign fields where the wells are shallow and cable is at a premium, while poles are one of the natural resources of the country.

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(1) A. Winchell, 'Sketches of Creation'. 1870.

(2) A photograph of a 'kicker' rig is shown in the Annual Report of the Ontario Department Mines, Vol. XXX, pt. V, page 55.

OIL AND GAS IN THE ONONDAGA AND DELAWARE FORMATIONS

The Oil Springs Field has produced continuously since 1861, and it is one of Ontario's most prolific sources of oil at present. The oil is found in the Delaware and Onondaga formations, cavernous limestones, in places dolomitic. The depth of the wells ranges from 350 feet to 400 feet, and the thickness of the oil-bearing portion is from 5 feet to 10 feet. The structure is a quaquaversal fold with a total closure of 50 feet. Several of the early wells flowed 2,000, 3,000, and 5,000 barrels per day, and one is credited with an initial flow of 7,500 barrels. These wells were dug down to the rock and cribbed with wood before the drill was started. It can be seen that such large wells were impossible to control, and so much oil escaped into Black creek that this sluggish stream assumed spring freshet conditions and the oil spread over lake St. Clair inches deep. No estimate can be made of the flush production of the Oil Springs field, but it might easily be millions of barrels, on the basis of initial flows (1). Only a few hundred barrels of this oil was saved, as, in these early days, there were no storage tanks available other than wood tanks of about 150 barrels capacity, and the problem of saving the flush production was acute. It was soon discovered that the Erie clay, which formed the subsoil in that locality, was impervious to crude oil. Extensive underground storage was then provided in pits, 60 feet deep and 30 feet wide, lined with wooden curb, and covered with a wooden top. These had a capacity of about 5,565 barrels. It is stated that the loss from evaporation was practically *nil*, and no disastrous fires are recorded. Many of these pits, or underground tanks, are still in existence.

There were 1,130 wells in operation in the Oil Springs field during 1925, and production amounted to 39,157 barrels, being an average of 34.6 barrels per well. The total oil recovered from this field to the end of 1925 is estimated as 7,400,000 barrels.

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(1) Geological Survey of Canada, Annual Report, Vol. V, 1890-91, p.7Q.

The Petrolia Oil Field, in Enniskillen, Moore, Sarnia, and Plympton townships, was discovered about the year 1862 or 1863, and flowing wells date from 1865. At its maximum, the field has an area of about 20,000 acres, but the present operated area is only about half that total. The drilling methods used in the early days were the same as in Oil Springs, and consequently the waste of oil was enormous. Probably more wells were drilled per acre in this field than in any other, this being due to the fact that land owners sold the oil rights in plots scarcely large enough to permit the erection of a drilling rig without trespassing. Subsequently, the gas was allowed to escape without restriction, the operators firmly believing that the gas retarded the flow of oil. In the Ontario Bureau of Mines Report for 1894, it is mentioned that the operators became aware of their folly in allowing the gas to escape so freely, and some years later installed vacuum pumps to increase the production of oil.

In this field, as at Oil Springs, the source of the oil is the Onondaga limestone. One driller states that rock shot out of a well was so soft that he could crush lumps of it between his teeth (1); this would indicate that the rock is honeycombed by infiltrating waters and is undoubtedly cavernous, for when a vacuum pump is exhausting gas from one group of wells, an air leak developing in a well outside the group will cause a rise of pressure in the group in two or three hours. The thickness of the oil-bearing horizon varies in different parts of the field, but in the central and eastern portion (the most productive) it is from 5 feet to 13 feet. In the northwestern part of the field, which is the least productive, the oil is reported by the drillers to occur in 'fissures' or 'crevices' in the rock. Wells along a certain strike will be found to be productive, while others within the same area give little or no oil. These 'crevice' wells have not a long life, but when closed down for a short time they appear to accumulate oil, for, when again pumped, the production is restored for a time. At present, these wells are operated intermittently, but those in the central and eastern part of

(1) A sample of oil-impregnated limestone from the Onondaga formation taken from a quarry at St. Mary's, shows these characteristics very clearly.

the field are operated at least for a few hours each day of the year. The production is probably less than a gallon of oil per day, but there are, or have been, as many as eighty wells pumped from a central power station by the 'jerk rod' method. In the early days, these central power stations were operated by steam engines using coal to raise steam; then gas engines were used, and within the last seven years electric motors have replaced these. Since the installation of electric power, shut-downs have been less frequent, and the recovery has slightly improved.

On account of the low price of oil during the last few years and the removal of the government bounty, maintenance of the wells has been practically abandoned. Wells are pumped so long as they will produce oil, but, if repairs are necessary, the production rarely justifies any great expenditure.

The Ontario oil in the Devonian limestone has a paraffin base and averages 35° Be., being high in gasoline and kerosene, and low in lubricants. All products are recovered, from gasoline to wax for candles. There is a pipe line from the town of Petrolia to the Imperial Oil refinery in Sarnia, and practically the whole production of the field goes there.

The total estimated production of the Petrolia field from 1861 to 1925, inclusive, is 15,090,700 barrels.

The Bothwell oil field, or at least a portion of it along the Thames river, was discovered about the year 1862. There were many wells drilled in the three years following, and a pipe line was laid to Bothwell station. These wells were mostly drilled by contract and a certain depth was specified; and the contractor, being human, would drill past the oil and complete the well to the contract depth. In this field, there is a water-bearing stratum (Oriskany sandstone) 20 feet or 30 feet below the oil horizon, and most of the wells were drilled into and past this water; consequently, when the United States operators abandoned their operations in 1866, at the time of the Fenian raid, the wells became flooded, and that portion of the field was ruined.

About the year 1895, following an improvement in the price of oil, this field was re-opened. In the intervening years, the operators had profited by thirty-five years experience, and scientific men had been attracted to a study of oil field problems. Among others, Dr. Sterry Hunt (1) and Sir William Logan (2) pointed out that, as oil floats on the salt water, it seeks the highest point of anticlinal folds. The later prospectors, among whom F. J. Carman is probably the most prominent, began to refer the depth to the top of the Delaware and Onondaga formations (then known as Corniferous) to the sea level, and sought the highest points in the structure; and thus it was that the Bothwell oil field, as at present known, was discovered.

The oil in the Bothwell field is found in the Delaware and Onondaga formations, at a depth below the surface of about 375 feet. The thickness of the oil-bearing strata probably averages eight feet. The character of the rock, as judged by an examination of the drill cuttings, differs from that of other Ontario fields, in that it appears to be a coarse granular dolomite, the grains, of even size, averaging 1½ mm. It is stained brown with the oil, and has every appearance of a sandstone. The oil occurs in four long, narrow pools on the top of an east and west ridge, which extends west past the village of Thamesville, where two more high points of the fold contain oil. This ridge is about 20 miles long and has a closure of from 80 to 120 feet. The summits of these oil pools are at elevations of 380 ft., 390 ft., 450 ft., and 460 ft., above sea level, and the oil extends about 10 feet to 20 feet down the dip.

Early in 1927, a new producing well was completed in this district, and since then further successful drilling would seem to indicate that another pool exists to the west of the four already mentioned.

The wells completed pump at the rate of about 12 barrels per hour, and the possible producing area is from 200 to 300 acres. Conditions appear to parallel those in the Thamesville-Bothwell pool.

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(1) Dr. Sterry Hunt, Canadian Naturalist, 1861.
(2) Sir William Logan, Geology of Canada (1863); pages 379 and 787.

The production of the Bothwell field was not reported separately from other fields until 1898, and for the years 1885 to 1898 is, therefore, an estimated portion of the total production for the Province based on the number of wells recorded and the history of the development of each field. This estimated and recorded production totals 2,156,757 barrels from 1885 to 1925.

There are many other small oil pools in the Onondaga formation throughout Essex, Kent, Lambton, Elgin, and Middlesex counties, the most important being those in the Mosa, or Glencoe, field, which had been partially drilled and abandoned many years before, but was re-opened in 1917 by Mr. F. J. Carman. The character of the limestone appears to be about the same as in the other Ontario fields, and the method of operations is the same. Although rediscovered so recently, this field has suffered from inexperienced operators, who had their wells drilled so deep that they penetrated the water-bearing Oriskany (?) sandstone below the Onondaga, and many parts of the field have, in consequence, been flooded with salt water. This field covers approximately 4,000 acres, and the total production from 1917 to 1925, inclusive, is 249,210 barrels. There are 74 wells operated, and 16 not operated, in the field, but these wells have not been so closely spaced as in the other fields described.

In the early days, the success or otherwise of the producers of crude oil in Ontario was in the hands of the refiners. The crude oil from these shallow fields contains an appreciable quantity of sulphur, which gives the oil an offensive odour, and when used for illuminating purposes without completely eliminating the sulphur, it leaves the wick and burner heavily incrusted with sulphur compounds. On the other hand, the oil from the Ohio and Pennsylvania fields contains practically no sulphur. Consequently, the Ontario refiners were seriously handicapped in competing with these United States oils, and the producers shared in this situation. Although the Ontario oil was treated with acid to remove the sulphur, the process was never commercially successful until about 1885, when redistillation after the acid treatment very greatly improved the product; but Ontario illuminating ils continued to suffer from the competition of the United

States oils, and commanded a somewhat lower price. However, the improved refining methods caused a sufficiently increased demand for the refined products to warrant an increase in the price of crude oil, and intensive development of Ontario oil fields followed, as is evidenced by the re-opening of the Bothwell oil field, and the discovery of the Essex and Welland county gas fields and some small pools elsewhere, the most important being the Shetland pool.

OIL AND GAS IN THE GUELPH FORMATION

The discovery of large gas and oil fields in the State of Ohio in 1885, on the summit of the Cincinnati anticline, suggested the probability that oil or gas might be found where this fold entered Ontario, in Essex county. A gas well of large volume, completed in February, 1889, midway between Kingsville and Leamington, proved the accuracy of this conclusion, and a new era of development began. In August of the same year, a test was made in Humberstone township, Welland county, which resulted in another large gas well and led to the development of the Welland and Haldimand gas fields.

The Essex gas field is on the margin of lake Erie, between the towns of Leamington and Kingsville. It is about six miles long and three miles wide. The gas is found at about 970 feet below the surface, in what is presumed to be the Guelph formation. There is a high-pressure water-bearing formation below the gas, and most of the wells drilled in this field were drilled into this water. The operators were mostly unskilled in gas-field practice, and allowed the water to flood the gas horizons as the gas was withdrawn and the pressure reduced. Instead of having a long period of small production following the flush production, the field ceased to produce gas very suddenly in 1903, after about nine years' service. The initial rock pressure was 450 pounds per square inch and, at the time the field ceased to produce, the pressure was reported as 310 pounds. Most of the gas from this field was exported to Detroit and Toledo. Export commenced in 1894 and ceased, to Toledo in July, 1900, and to Detroit on December 10th, 1901. The total production of the field is estimated by Mr. Eugene Coste as 22,000,000 M. cubic feet.

Gas, in these early days, was sold to domestic consumers mostly on a flat rate, and was disgracefully wasted. Large volumes were measured by the Pitot tube, and all that can be said for it is that the measurement was as accurate as the operator's skill in setting the tubes in the pipe line. Production figures are estimates based on average quantities used in this manner.

The loss of this gas field has been a great object lesson to natural-gas producers in Ontario. The result has been that the operators now use greater care in drilling wells and pay more attention to the study of water problems, while the Province appoints an Inspector to supervise all field work, especially the plugging of wells.

The Leamington oil field, discovered in 1904, is about eight miles long and from half a mile to one mile wide. It lies at right angles to, and at the eastern end of, the gas field, and is in the same formation, but structurally 100 feet lower. The shape of the field suggests a slight fault.

Also in the Guelph formation are the gas fields in Kent county, the southernmost oil pool in Romney township, the oil field in Tilbury East and Raleigh townships, two oil pools on Pelee island (1), and a small isolated pool in West Nissouri township, Middlesex county.

The wells in *the Kent oil fields* were not so large as those in Oil Springs and Petrolia, nor was the life of the average well as long. The summit, and the major portion, of the largest structure in the county is occupied by gas (the Tilbury gas field), and the oil is confined to a relatively small area, apparently on a lower fold in a northern extension of the field. There are two small oil pools—a shallow one in the north part of Romney township, in the Onondaga formation, and another (previously mentioned) in the southwest portion of the township, in the Guelph formation. A well that was unique in some respects was drilled in 1902 in lot 18, concession XII, of Raleigh township, to a depth of 460 feet, finishing in the Onondaga formation. This well flowed 1,000 barrels per day for some time, but settled down to a production of 25

(1) Geological Survey of Canada, Map No. 1826.

barrels per day by pumping. Its life was about one year. Of all the other wells drilled in this vicinity, only a few gave commercial production.

By far the most important field in Kent county is *the Tilbury gas field.* It lies mainly in Tilbury East township, but extends into the adjacent townships of Romney and Raleigh. The field is rudely triangular in shape, with its base extending nine miles along the shore of lake Erie and its apex situated seven miles inland. It has served a population of 215,000 with 135,687,150 M. cubic feet of gas within a period of twenty years. This figure does not include leakage for the first fifteen years, which would add another 20,000,000 M. cubic feet. The rock pressure has declined in this time from about 750 pounds per square inch to 300 pounds. This field will continue to supply some gas for perhaps another fifteen years, but its production will be unimportant by that time. It is presumed that a large extension of the field lies under the waters of lake Erie.

There are from two to four producing horizons in this field, the thickness of each varying widely. They appear to be lenses, and are met with at odd intervals over a depth of one hundred feet; they are, therefore, not easily correlated. On this account it is difficult to determine the structure. but, judging by the top of the dolomite described below, there appear to be a major and two minor folds of very uncertain closure. The rock appears to be similar in character to that of the Leamington gas field; it is a blue-grey coarse-grained dolomite, either at the bottom of the Salina or the top of the Guelph formation. The contact of these formations is covered with drift at the outcrop, and, if this particular member is there present, it has never been seen. The dolomite is very cavernous, and wells as much as three hundred yards apart are interconnected. The underlying formation is filled with water under considerable pressure, as was found in the Leamington gas field, and wells drilled into this formation require, as a rule, continuous pumping. There is also some gas in this water-bearing stratum. The gas contains about three-tenths of one per cent of hydrogen sulphide, which has a very corrosive effect on pipe, meters, regulators and,

especially, on brass coils in water heaters. Another objectionable feature is a black dust (mixture of ferrous and ferric sulphates) which is carried along through the pipes, clogging all moving parts of meters, regulators and valve seats, and which, lodging on the discs of orifice meters, affects the measurement of the gas. After one very expensive failure, a process has now been perfected which successfully removes the hydrogen sulphide from this gas.

About two years ago it was discovered, while abandoning and plugging a well, that the tubing was filled with salt just above the gas horizon. After clearing this obstruction and discharging 250 pounds of dynamite at the bottom of the well, the salt was removed and the flow of gas restored to within 25 per cent of its original volume. Since this time, all of the 260 wells in this field have been examined, and those suspected of containing salt have been similarly treated, the field thereby being rejuvenated. This deposit of salt is no doubt caused by the rise and fall of the salt water in the wells, and, where the gas bubbles through the water, it assists this deposition.

The gas fields in Dawn township and at Oil Springs in Lambton county are also in this member of the Guelph formation; both fields are small in both area and production.

OIL AND GAS IN THE CLINTON AND MEDINA-CATARACT FORMATIONS

The gas in *the Welland-Haldimand field* is found in the Clinton and Medina-Cataract formations. The productive horizon of the Clinton is in the uppermost three feet of that formation, and is very porous and light grey in colour. There are two productive horizons in the Medina-Cataract, the Grimsby and the Whirlpool, both sandstones. The Grimsby member, which is 35 feet thick at Niagara falls, is a fine-grained red to mottled sandstone that passes from a sandstone in the Niagara peninsula to a sandy shale, and finally merges into the underlying Cabot Head shale in the west. The

Whirlpool sandstone, which ranges from a few feet to 40 feet in thickness, is fine, even-grained, and grey in colour. As a rule it is quite porous, and makes an excellent reservoir, but in places it is non-productive, apparently being cemented with calcium carbonate. These formations are productive throughout the counties of Welland, Haldimand, and Norfolk, and the western third of Elgin county, and also over an area six miles in depth extending along the northeast side of the Grand river, from Brantford to Haldimand county and the same portion of Wentworth and Lincoln counties lying along the border of Haldimand; they are non-productive to the southwest, and are absent to the north, of the district outlined. There is only one small oil field in these formations. It was discovered in 1903, and is southeast of Brantford, in Onondaga township. Some gas is found in the Clinton, but the oil is found only in the Whirlpool sandstone. The usual order of separation met with in oil and gas fields is here reversed. Considering the Haldimand field as a whole, and not the individual wells, the oil is considerably higher, structurally, than the gas (see key map, Figure 2).

The Welland field, discovered in 1889, has been producing steadily since that date, and supplies at present a population of 50,000. In recent years, export of the gas has been prohibited, but from 1891 to 1907 the demands of the city of Buffalo were partially met. Production to date has amounted to approximately 37,000,000 M. cubic feet from the more than one thousand wells which have been drilled. *The Haldimand and Norfolk fields* are inter-connected by pipe lines, and their production cannot be separated. Together, they have yielded, from 1900 to date, about 52,000,000 M. cubic feet, and the population supplied has been about 100,000. There were from 3 to 6 producing wells at Caledonia in 1903, but the production following that date is unknown.

In the great area described above, comprising approximately 685 square miles, gas is found in large or small pools in any one or all three of the formations described. The capacity of the wells appears to bear a greater relation to

the character of the rock than to its attitude. There are very few folds, and those that have been outlined by building up structure-contour maps are radial to the Appalachian basin, *i.e.*, parallel to the dip. There is one marked fold running slightly east of north through point Albino, Welland county; another runs due north through Canboro township and is reflected in Caistor; another appears to pass through Seneca township, commencing at the village of York and continuing northward to Binbrook township in Wentworth county, with parallel folds to the eastward. There is folding of uncertain dimensions in the southwest corner of Woodhouse township, and a fold in Elgin county running slightly northeast through the Bayham gas field. A study of these conditions leads one to the conclusion that the nature and thickness of the sediments, and not the folding, controls the rate of production. The folds are very gentle and have no closure on their northern extensions. The field work done has been of a preliminary nature, and the information gained is neither accurate nor complete.

All of these strata thin out to the northwest, and consequently the most productive wells are found along the margin of lake Erie, and especially in Welland county.

The gas field mentioned, and the gas fields in the same formation in eastern Ohio, form a great crescent which passes under lake Erie and forms the northern and western rim of the Appalachian basin. These formations are no doubt the shore-line sands of ancient seas and, if so, the waters of lake Erie cover a large potential natural-gas reservoir.

HELIUM GAS IN THE DUNDAS FORMATION

A small gas pool, about 30 miles northwest of Toronto, in Caledon township, Peel county, is now being exploited. The volume is small and the rock pressure is about 50 pounds per square inch; but the gas contains eight-tenths of one per cent of helium, and is the richest in this element yet found in the British Empire. The helium content of Ontario

natural gases has been fully discussed by R. T. Elworthy in a report published by the Mines Branch of the Department of Mines, Ottawa, July 17th, 1925. The gas in Caledon township occurs in the Dundas formation at many depths from 300 feet to 600 feet below the surface. It finds a reservoir in the impure limestones, or possibly the sandy shales, in this formation. No structure is evident that would form a trap for gas. The capacity and pressure of the pool is not great enough to make it of commercial importance, but the helium has great value for research purposes.

OIL AND GAS IN THE TRENTON AND BLACK RIVER FORMATIONS

The deepest Palæozoic formation in southwestern Ontario, the Trenton and Black River limestones, and especially the latter, are impregnated with petroleum and, when penetrated by the drill, nearly always give a small production of from one to five barrels per day, accompanied by gas. Yet in only three places has a commercial production been obtained, *viz.*, in Dover township, Kent county; in Amabel township, Bruce county; and at Oil Springs, where one well is supplying most of the gas used in the village. Several small gas and oil wells have been drilled along the south shore of Georgian bay, and at Wekwemikong in Manitoulin island. Sufficient logs are not available to determine what the structural condition may be in Amabel, but in the Dover field it is very suggestive of a fault of considerable magnitude, with the accumulation on the downthrow side. The limestone in this field contains varying amounts of magnesia and is quite dense, but it has many solution cavities and it is in these that the oil and gas undoubtedly occur. The Trenton and Black River formations are from 550 feet to 800 feet thick. At the Niagara escarpment, they are at about 1,600 feet below the surface, and in Dover township, at 2,900 feet. The Trenton is inclined to be thin-bedded, while the Black River is more massive, the beds being separated by thin bands of shale. Examination of the

structure-contour map of these formations (1) shows the dips to be quite gentle, averaging twenty feet per mile, with several areas suitable for accumulation. The Trenton has been sparsely tested in the Province and there is the possibility of further development.

At the base of the Black River limestone there has been found a band of white shale, 40 feet thick, and immediately under this a bed of very hard, white sandstone that rests on the basal arkose which overlies the pre-Cambrian. Unfortunately, the drill cuttings do not give any further evidence of its character. This sandstone, as a rule, holds water under great pressure, but in a few cases it has contained oil, notably in the eastern corner of Romney and in Onondaga township. The Romney well spouted oil over the top of the derrick and pumped 16 barrels of oil a day for well over a year, although handicapped by mechanical difficulties. The oil was found at 3,560 feet below the surface. A well in Onondaga township gave a production of 5 barrels per day from this horizon.

OIL SEEPAGES AND SURFACE GAS

A seepage of petroleum residue occurs in the quarry at St. Mary's, Perth county, and what has all the appearance of a seepage of waxy residue occurs in Wellesley township, Waterloo county. An astonishing quantity of gas occurs in the thick mantle of glacial drift which covers southwestern Ontario, and wells with a capacity of three million cubic feet per day have been drilled. Seven wells west of Ridgetown have delivered, during the past two winters, 106,681 M. cubic feet of gas to the town of Ridgetown. Other important occurrences are at Sarnia, in Lambton county, and at Beeton, in the southern part of Simcoe county. The life-time of these surface wells is, in many cases, as much as fifty years, whereas the average natural gas well has an average life of only 15 years.

(1) Ontario Department of Mines, Vol. XXXII, pt. V, 1922.

OIL AND GAS PROSPECTS OF THE GREAT PLAINS OF WESTERN CANADA*

By G. S. Hume (*Member, C. Inst. M. & M.*)**

Physiography

The Great Plains area of western Canada stretches from the western edge of the pre-Cambrian Shield in eastern Manitoba to the foothills of the Rocky mountains in western Alberta. Within this great area there are, in southern Canada, three prairie levels, or steppes, with a gradual upward slope from the east to the west. The most easterly of these prairie levels is the Manitoba lowlands, underlain by rocks of Palæozoic age. It has an average elevation of about 800 feet above sea-level and drains to Hudson bay. It is separated from the second prairie level by an eastward-facing escarpment which forms the eastern edge of the Cretaceous and younger sediments of the Western Plains area. Drainage channels from the second to the first prairie level divide the escarpment into several plateau areas, known as Pembina, Riding, Duck, Porcupine, and Pasquia hills, the summits of which rise 500 to 1,000 feet above the Manitoba lowlands. The second steppe slopes upward in a southwest direction into the third steppe, which continues to the foothills of the mountains, rising from an elevation of less than 1,500 feet to more than 4,000 feet. In the central part of Alberta and Saskatchewan, there is no break between the second and third steppes, but in the south the two are roughly separated by an eastward-facing escarpment which is the continuation into Canada of the Missouri coteau of United States. According to Rose (1), this escarpment is the eastern boundary of the Wood Mountain-Willowbunch plateau, which rises 200 to 500 feet above the second steppe. This plateau area, however, does not represent a rise which is continued without break to the foothills, but on the western side of Wood mountain

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**Geological Survey of Canada.

(1) Rose, B.: Wood Mountain-Willowbunch Coal Area, Sask.; Geol. Survey of Canada, Mem. 89, p. 13 (1916).

there is a descent almost equal to the escarpment on the eastern side. To the west, partly in Alberta but mainly in Saskatchewan, lie the Cypress hills, a plateau that rises several hundred feet above the prairie level and, like the Wood Mountain plateau, represents an erosion remnant within the third prairie level.

STRATIGRAPHY AND GEOLOGICAL HISTORY

Within the physiographic divisions of the Great Plains there is a wide diversity in the age of the rocks represented in each. The range is as follows:

Glacial and Recent Deposits

Boulder clay, gravels, and sands, mostly unconsolidated, are widely spread over the whole area.

Tertiary

In central Alberta, south of North Saskatchewan river, there is a large area covered by Tertiary deposits of the Paskapoo formation. In southwestern Alberta, Tertiary sediments comprise the upper part of the St. Mary River, the Willow Creek, and the Porcupine Hills formations. In the Cypress hills, conglomerates of Oligocene age are known. In southern Saskatchewan and Manitoba, Tertiary sediments are represented by erosion remnants in the Cypress hills, in the Wood Mountain-Willowbunch area, and in the Turtle mountains.

Mesozoic

Cretaceous.—With the exception of those areas covered by Tertiary sediments, Cretaceous deposits cover the entire second and third prairie levels as outlined. East of the area covered by Tertiary rocks in central Alberta, the surface of the plains levels the Cretaceous, so that, in general, progressively older Cretaceous formations appear eastward, the eastern edge being the escarpment at the division of the first and second prairie levels.

Jurassic and Triassic.—Rocks of these ages outcrop only in the mountains and foothills, where they have been exposed by faulting or folding. They undoubtedly extend eastward for some distance under the plains, but the eastern limits are unknown. Jurassic sediments are known from well-borings in southern Alberta, but have not been recognized elsewhere.

Palæozoic

Permian and Carboniferous.—These are known only in the mountains and foothills, but, like the Jurassic and Triassic, they undoubtedly extend for some distance under the Plains. Carboniferous strata are known in well-borings of southern Alberta, but have not been recognized in the central or northern Plains areas.

Devonian, Silurian, and Ordovician.—These underlie the Manitoba lowlands and the Devonian outcrops in the Athabaska River section immediately underlying the tar sands of the Cretaceous in the McMurray (Alberta) area.

GEOLOGICAL HISTORY

The Palæozoic formations overlap onto the pre-Cambrian of the Canadian Shield in eastern Manitoba. In Manitoba, and in at least central and northern Saskatchewan and Alberta, Cretaceous sediments are presumed to lie directly on the Devonian. The unconformity separating the Devonian and Cretaceous represents an exceedingly long interval of time in which, presumably, a large amount of erosion occurred in the east but which in the west was, at least in part, a period of deposition. Carboniferous, Permian, Triassic, and Jurassic marine sediments are known from the foothills and mountains, and were deposited in seas which overlapped for an unknown distance the older sediments. Since the oldest Cretaceous sediments are believed to be continental deposits, it is assumed that there was a pre-Cretaceous period of erosion, in which the area now occupied by the plains was above sea-level. Probably the sediments of Jurassic, Triassic, Carboniferous, and Permian ages were

bevelled off during this period of erosion and may have been entirely removed over areas where they formerly extended. In the mountains of southern Alberta, thick deposits of these ages are preserved, and it is concluded they have a wedge-like form with the thick portion of the wedge in the mountains in the west and the thin edge at an unknown distance under the plains east of the foothills. Following this period of erosion, continental deposits of Cretaceous age were widely distributed over the Great Plains. In these sediments, sands predominate over shales, and in some areas conditions were favourable for the formation of coal deposits. It is not assumed that the Lower Cretaceous sediments over the whole Plains area are exact equivalents, but it is probable sediments now found in one portion of the plains may represent only part of the time represented by sediments found in other parts, or, in certain cases, the sediments in two areas may belong to entirely different parts of the Lower Cretaceous. Such formations of Lower Cretaceous age are the Kootenay and Lower Blairmore of southwestern Alberta; the McMurray, Clearwater, and Grand Rapids formations of the Athabaska area; the Loon River and Peace River formations of the eastern Peace River area; the Bullhead Mountain, and possibly younger, formations of the western Peace River area; the basal Cretaceous sands of the Manitoba area; etc.

The Lower Cretaceous was followed by thick shale deposits of Colorado age, with a marked thickening from east to west. In the Peace River area, the Dunvegan sandstone is a non-marine member of the Colorado, but elsewhere the sediments are mostly marine shales with some sand members near the base. The Montana deposits, following the Colorado, began in certain places in Alberta as marine shales but were quickly followed by deposits of great thickness of the Belly River, a delta deposit with marine members. The total thickness of the Belly River is quite variable—from less than 1,000 feet in certain parts of eastern and southern Alberta to 10,000 (1) to 11,000 feet in the foothills southwest of Edmonton.

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(1) Allan, J. A. and Rutherford, R. L.: Saunders Creek and Nordegg Coal Basins, Alberta; Sci. and Indust. Research Council, Alberta, Report No. 6, 1923.

In southern Alberta, the Belly River deposits are followed by marine Bearpaw shales, which in turn are followed by the extensive and coal-bearing beds of Edmonton and equivalent age. In central Alberta, it has been shown (1) that a disconformity separated the Edmonton from the overlying Paskapoo formation of Tertiary age, but it is not known what relationship this unconformity has to the Lance formation of southeastern and southwestern Saskatchewan. The Lance formation has dinosaurs later in age than the Edmonton, and Lance dinosaurs are known in the Estevan beds of the Cypress hills. The relationship of the Lance to the formation in central Alberta is not clear.

Tertiary rocks of Paskapoo age occupy a wide area in southern central Alberta, extending from the International Boundary to slightly south of Athabaska river northwest of Edmonton. There are also small isolated areas outside of this larger area, and Tertiary rocks cap such prominent features as House mountain in the Swan hills, Hand hills and Cypress hills. The Tertiary rocks are coal-bearing in Cypress hills, Wood Mountain-Willowbunch area, and Turtle mountains of Manitoba. These areas of Tertiary rocks are erosion remnants of a much more extensive and probably continuous area which formerly covered the southern Great Plains of Canada to an unknown extent and thickness.

It is certain that only part of Tertiary time was a period of deposition in the Great Plains areas, and prior to the glacial epoch a great amount of erosion was accomplished. In this period of erosion, the Tertiary was stripped from areas, leaving erosion remnants capping the higher topographic features of Alberta and being preserved in the downwarped area of the Alberta syncline. Following the Tertiary, the whole of the Great Plains was glaciated. Two ice sheets were involved, one from the mountains—the Cordilleran ice sheet—which, according to Coleman (2), was in southern Alberta at least older than the other, or Keewatin, ice sheet. The eastward limits of the Cordilleran sheet are unknown,

(1) Allan, J. A.: Geology of Alberta Coal; Trans. Can. Inst. of Min. and Met., Vol. XXVIII, 1925, p. 231.

(2) Coleman, A. P.: The Drift of Alberta and the Relations of the Cordilleran and Keewatin Ice Sheets; Trans. Royal Soc. of Canada, 1909, Sect. IV, pp. 3-13.

but it probably covered a relatively small portion of the Plains area in comparison with the Keewatin sheet. Over the whole of the Great Plains, deposits of boulder clay and glacial materials were widely distributed, and to a certain extent there was a re-arrangement of drainage. However, it has been demonstrated that at least a number of the main drainage channels antedate the ice sheets, and the amount of erosion that has taken place since the glacial epoch is relatively slight in comparison with the erosion that was accomplished in Tertiary time.

STRUCTURE

The folding and faulting which characterizes the foothills gradually dies out eastward, and over much of the Plains area the strata depart from the horizontal by only a few feet per mile. In southern Alberta east of the foothills, a great syncline or downwarp has been developed which, to a large extent, probably explains the preservation of the Tertiary sediments in central Alberta south of Lesser Slave lake. In southern Alberta this syncline or basin is much narrower than further north, and east of it lies an upraised or anticlinal area known as the Sweetgrass arch. The Kevin-Sunburst oil field of Montana has been developed on this structure, but in Canada the arch plunges downward to the north, and although subsidiary folds have been found on the najor structure, only gas fields have so far been developed in Canada. These gas fields include the Bow Island and Foremost fields, as well as other prospective fields. Recently the Imperial Oil Company has drilled a deep test on the Bow Island structure, the gas horizon of which is in the lower part of the Colorado shales. This test encountered an oil sand in what is presumed to be Lower Cretaceous or Jurassic strata, but commercial production was not obtained at that horizon; and although the well was carried to a considerable depth in the underlying limestone, no further oil shows were met with.

From the Sweetgrass arch, the rocks dip radially, and, in a northeast direction at some considerable distance down the dip, the Medicine Hat-Redcliff gas field has been developed

on a local fold. The main gas horizon of the Medicine Hat-Redcliff area is the Milk River sandstone which, in southern Alberta, is the basal formation of Montana age. A deep test (Roth No. 1 well) found gas production in the Milk River sandstone, but no commercial oil or gas production at a lower depth. A second deep test (Roth No. 2) is now in progress. It is interesting to note that up the dip from the Medicine Hat-Redcliff area in the Milk River sandstone an artesian water area occurs, the edge of the Milk River sandstone outcropping along Milk River ridge on the Sweetgrass arch. To the east of the Medicine Hat area, and presumably still further down the dip, gas occurs in the Many Island Lake district. The local structure at this place is not known.

In eastern central Alberta, the eastern edge of the Alberta syncline is thought to be a line from Misty hills, south of Monitor, in the south, to the west of Viking in the north. West of this line the strata plunge downward in a southwest direction into the Alberta syncline, whereas eastward, although the regional dip is in the same direction, it is much more gentle in character. Recent work of the Geological Survey has shown that this moderate, regional, southwestern dip is continuous from west of Viking to the Alberta-Saskatchewan boundary in the vicinity of Battle River, but east of this the dip is southeastward. It is known that this easterly dip continues almost to the town of Battleford, but its extension in a southeast direction is unknown. The crest of the major structure is, therefore, in the vicinity of the Alberta-Saskatchewan boundary at Battle River. West of this, on the gentle southwest regional dip, a number of local folds have been shown to be present, and these have given the Viking gas field, which supplies Edmonton and intermediate centres of population; the Hawkins fold, on which one gas well has been drilled; the Fabyan fold, on which two wells have been drilled, both of which have a capacity for large gas production and one of which contains a small amount of heavy oil; the Wainwright-Battle River fold, on which several oil wells have been drilled but in which the gas production is much less than in wells on the Fabyan fold; and, at the crest of the regional anticlinal

structure close to the Alberta-Saskatchewan boundary, the Ribstone-Blackfoot anticline, which is now being tested by three wells. About 12 miles northwest of the Ribstone-Blackfoot anticline, there is a well-marked syncline with the bottom of the syncline at least 275 feet below the crest of the Ribstone-Blackfoot anticline on the base of the Belly River sediments. The Ribstone-Blackfoot anticline is, therefore, itself a local fold which, however, corresponds in position with the crest of the regional anticlinal structure. It is known that there is closure on the southwest and southeast sides of the Ribstone-Blackfoot anticline greater than the 275 feet on the northwest, but the closure in a northeast direction is entirely unknown and it is possible none is present. The lack of outcrops in a northeast direction makes the determination of closure impossible, except by drilling. It is thought the crest of the Ribstone-Blackfoot anticline has a trend slightly east of north, whereas the Hawkins, Fabyan, and Wainwright-Battle River folds undoubtedly trend in a northwest and southeast direction.

OIL AND GAS HORIZONS AND PROSPECTS

The highest productive gas horizon within the Plains area is found in the Milk River sandstone, which is the basal formation of the Montana in the Medicine Hat-Redcliff area. It is thought the Milk River sandstone is thickest at its outcrop on Milk River ridge, on the Sweetgrass arch, but it thins to the northeast to about 30 to 50 feet at Medicine Hat, where it is reached by the drill at a depth of 1,800 to 2,200 feet, depending on the elevation of the top of the wells. The initial open flow of the wells in this area was from 2 to 5 million cubic feet, with a rock pressure of 550 lb. in the early stages of production. *The Medicine Hat-Redcliff field* has been producing since 1908, and the gas is used for local domestic and industrial purposes (See map, Figure 2).

While other horizons of Montana age have given a small flow of gas in a number of places, there has been no sustained production of any magnitude; and although it may be said the prospects have been somewhat restricted by drilling already done, they have by no means been exhausted.

Perhaps the most persistent oil and gas horizon of the Plains area is the sands near the base of the Colorado shales. It is from these that the gas production has been secured in the Bow Island, Foremost, Viking, and Fabyan fields, and they constitute one of the oil horizons in the Wainwright-Battle River field as well as yielding gas in a number of places where, on account of the lack of demand for gas, extensive development has not yet been undertaken.

Information regarding *the Bow Island field* has been mainly derived from a report by W. S. Dyer (1). The fold has a closure of about 50 feet, but for such a small fold the gas yield has been very large. In the initial stages of the field, the wells had an open flow up to 18 million cubic feet per day, with one well having a capacity of 29 million cubic feet when first drilled. The original pressure of the wells was 700 lb. to 800 lb. per square inch, but owing to continued use of the gas for a number of years this pressure is now much less. Edge water is now beginning to encroach on some of the wells, and a few have been abandoned, but the field is by no means yet exhausted. The gas sand has a thickness of approximately 35 feet and is reached in wells at a depth of from 1,800 to 2,200 feet according to the elevation of the well and its location on the fold. For many years prior to the recent developments in Turner valley, the Bow Island field constituted the main supply of gas for Calgary and a number of smaller centres of population. In 1924, however, this supply was augmented by gas from the Foremost field.

The Foremost field is almost directly south of the Bow Island field. A number of wells have been drilled and these have shown an initial capacity of from 10 to 20 million cubic feet. The wells are from 2,000 to 2,250 feet in depth.

The Viking gas field is about 80 miles southeast of Edmonton. The amount of closure and the extent of the field are at present unknown. Twelve wells have been drilled by the Northwestern Utilities, Ltd., and these have yielded an initial capacity of two to nine million cubic feet each, with one well slightly under this minimum amount. The

(1) Dyer, W. S.: Unpublished manuscript in the possession of the Geological Survey of Canada.

depth to the gas horizon is from 2,100 feet to slightly more than 2,400 feet in two wells. Gas from this field supplies Edmonton, Viking, and intermediate points. The gas is a dry gas, with methane as the chief constituent, and no sulphur. According to Elworthy (1) the supply of gas in the immediate field is calculated to be over 60 billion cubic feet. The initial pressure of wells in this field was about 800 lb.

The Fabyan field is about 150 miles southeast of Edmonton and 8 miles west of the Wainwright-Battle River oil field. The fold which constitutes the Fabyan field has not been well defined, but enough is known to leave little doubt that this fold is separated on the east by a syncline from the Wainwright-Battle River fold, and on the west by another syncline from the Hawkins fold. The trend of the fold is thought to be northwest and southeast. Only two wells have been drilled on this fold. The first of these is the Imperial (Fabyan) No. 1 well, which gave a flow of about 10 million cubic feet of gas and a small amount of heavy oil. The other is the Maple Leaf No. 1 well, which gave only gas. The gas from the Maple Leaf well has only recently been piped to Wainwright, so that the field will in all probability be developed as the demand for gas increases.

The Wainwright-Battle River oil field is 4 to 5 miles almost directly north of Wainwright. A number of wells have been drilled and two oil horizons are known, the upper one being in sands at the base of the Colorado shales and the lower in sands presumed to be of Lower Cretaceous age. Two wells, No. 2 and No. 4 British Petroleums, have yielded oil of about 12 degrees Beaumé from the upper horizon at a depth of slightly more than 2,000 feet, and No. 2 well contains a considerable volume of dry gas. The Wainwright-Battle River fold is thought to parallel the Fabyan fold to the west of it, and extends for an unknown distance in a northwest and southeast direction. Presumably it crosses the Battle river, and the prospects north of the river should be equally

(1) Elworthy, R. T.: Natural Gas in Alberta; Mines Branch, Dept. of Mines, Pub. No. 616A, p. 17, 1925.

as good as those to the south, where all the wells so far drilled are located—provided, of course, the oil sands do extend to the north of the river. The closure of the fold is unknown, but is not thought to be great and may not greatly exceed 50 feet on the northeast flank. A noticeable physiographic feature of some importance in relation to the Hawkins, Fabyan, and Wainwright-Battle River folds is the fact that, on each of these folds, the Battle river makes a southward bow, this being particularly marked in the case of the Hawkins and Wainwright-Battle River folds. It is known that certain parts of the Battle River valley are pre-glacial in origin, and it is suspected that these bows in the river are due to the influence of structure. If such is the case, it might be concluded the lower part of the structure would be to the south, as this is the direction which the river followed in passing over the structure. On such physiographic evidence, therefore, it might be argued that the higher part of the Wainwright-Battle River fold would be to the north of the river and consequently the oil prospects on the fold north of the river might be more favourable than to the south, where all the drilling has so far been done. This question of structural detail could be settled at a comparatively small cost by the drilling of a number of shallow holes, since it is known that recognizable horizons would be encountered at no great depth from the surface. A determination of the character of the structure would at once show whether or not drilling for oil was justified north of Battle river.

The third productive oil and gas horizon within the Plains area is the Lower Cretaceous sediments. In south-western Alberta, the Lower Cretaceous is represented by the Blairmore and Kootenay formations, but the exact equivalents of these under various parts of the plains are unknown. In the Wainwright-Battle River fold, the lower productive oil horizon occurs below a coal seam and in what is assumed to be Lower Cretaceous sands. No. 3B British Petroleums well, Edmonton-Wainwright wells, and Western Consolidated No. 2 well, encountered production

of 19 to 20 degrees Beaumé oil at a depth slightly in excess of 2,200 feet from this horizon. Recently, the Imperial Oil Company, drilling on Ribstone-Blackfoot anticline, found a considerable volume of gas at 1,400 feet, and an oil sand at 1,900 feet. These two horizons have not been definitely correlated with the two productive horizons of the Wainwright field, but it is assumed the upper horizon is in the Colorado shales and the lower in the Lower Cretaceous. The lower horizon in the Imperial well has not yet been proved to contain a commercial supply of oil, but it is still hoped production may be secured on other parts of the area, as the structure seems favourable.

In the Athabaska River area, near the mouth of Pelican river, gas in quantity has been proved to be present in strata presumed to be the southwestward extension of the McMurray 'tar sand' formation, which is Lower Cretaceous in age. Owing to the lack of demand for gas in this area, no recent development has taken place.

In the lower Peace River area, extending from the town of Peace River northward for 15 miles, a number of wells have been drilled and small quantities of oil and gas have been found. The oil and gas occurs in the Loon River formation of Lower Cretaceous age. No commercial production has been secured and the structure, as far as known, is a broad, gentle fold with crest somewhere in the vicinity of Tar island, on Peace river. In the western Peace River area, at Pouce Coupe, the Imperial Oil Company drilled a well which, at 1,675 feet, apparently in the St. John shales, struck a flow of 10,000,000 cubic feet of gas. The age of the St. John shales is not definitely known, but the ower part may be Lower Cretaceous.

In the foothills and mountains there is a great thickness of Jurassic, Triassic, Permian, and Carboniferous strata between the Cretaceous and the Devonian. As has been shown in this paper, these formations wedge-out in an eastward or northeastward direction, and in the McMurray area of Athabaska river the Lower Cretaceous rests directly on

Upper Devonian limestones. In southern Alberta, however, there may be prospects for oil or gas in the Jurassic, as the Ellis sand of Jurassic age is one of the productive horizons in the Kevin-Sunburst field of Montana, and from well borings the Jurassic is known to be present in Canada near the International Boundary, on the Sweetgrass arch. Fossils of Carboniferous age have also been recognized in the Drazen well in the Many Island Lake area east of Medicine Hat, but there is some doubt as to whether this is the same age of Carboniferous that is productive in the Kevin-Sunburst area. The prospects for oil in strata of Jurassic and Carboniferous ages in central and eastern southern Alberta are, therefore, not determinable, although it is understood 'shows' of oil and gas have been encountered in a few wells in both.

Since it is assumed that Cretaceous sediments rest on the Devonian limestone over central eastern Alberta and western Saskatchewan, extending northwestwards to the Athabaska area, the only possible lower productive horizon in this area within reach of the drill is in the Devonian. 'Shows' of oil were reported from the Imperial (Fabyan) No. 1 well, drilled on the Fabyan fold west of Wainwright, from near the top of the Devonian limestone, but although the well was drilled over 550 feet into the limestone no further 'shows' were recorded. The horizon of the Devonian penetrated in this well is unknown. In the Great Slave Lake area, 500 miles north of Edmonton, the Middle Devonian is in part a very porous dolomite that yields copious seepages of oil. In the McMurray-Athabaska region, core wells drilled for salt (1) have shown conclusively that this character of the Middle Devonian is not present, and while no statement can be made regarding the lithology of the Devonian other than in very local areas where it has been partially penetrated by the drill, there is no evidence at hand to suggest it might be found to be a productive oil horizon under the Plains area. On the other hand, however,

(1) Second Annual Report on the Mineral Resources of Alberta, 1920. pp. 111-112.

the data on the Devonian are so limited in this area that any predictions, either negative or positive, regarding its oil prospects are valueless.

In conclusion it may be said that, as far as present knowledge regarding the Plains is available, the best prospects so far developed for gas and oil are the sands at the base of the Colorado shales and sands in the Lower Cretaceous sediments. The production in the Milk River sand of Medicine Hat-Redcliff area is an exception to the above statement, and various other parts have shown a small gas production from rocks of Montana age, so that there are possible undeveloped prospects of this age. In southern Alberta there are possible prospects from horizons corresponding in age to the productive sands of the Kevin-Sunburst field of Montana, while in central eastern Alberta and western Saskatchewan prospects older than Cretaceous would seem to be confined to possibilities of production from the Devonian.

In regard to a great portion of the area of Saskatchewan and Manitoba, the oil prospects will depend on the amount of folding that is present and to what extent these folds can be located. This whole area is covered by extensive deposits of glacial origin, and outcrops are almost totally concealed except along stream and river valley, so that, even though folds may be present, they will be very difficult to locate. At present none are known.

OIL AND GAS DEVELOPMENT IN THE FOOTHILLS BELT OF ALBERTA AND BRITISH COLUMBIA

By O. B. Hopkins (*Member, C. Inst. M. & M.*)*

General Description of Area

The 'Foothills Belt' lies between the Plains on the east and the Rocky mountains on the west, and extends from the International Boundary in a northwesterly direction to the Peace river. It has a variable width of 10 to 30 miles, a length of 600 miles, and embraces an area of about 12,000 square miles.

From the International Boundary northward to the vicinity of Bow river the area is only partly timbered and is covered with numerous ranches. Northward from the Bow river it becomes more heavily timbered, with ranches less frequent, until it is inhabited only by scattered trappers and Indians, excepting in the immediate vicinity of the intersecting railways.

The southern part of the area is largely accessible over the numerous roads that traverse it; the middle and northern parts are almost without roads, and access is had over the railways that cross it, and over a few scattered trails. Travel is very difficult off these trails, due to the deep muskeg which is commonly present and to large areas of fallen trees, called *brule.*

Topography

As suggested by the name 'foothills belt', the area is characterized by high hills and deep valleys, which become less pronounced from the mountains towards the plains. The foothills are sharply limited to the west by the mountains which rise abruptly from them, but they merge gradually into the plains to the east. The general elevation of the area

*Chief Geologist, Imperial Oil, Limited.

decreases gradually from 3,500 to 6,000 feet in its southern part to 1,200 to 4,500 feet in its northern extension. The hills rise from a few hundred to twenty-five hundred feet above the adjacent valleys.

The region is drained by numerous clear, swiftly flowing streams, which flow from the southern part of the area into Hudson bay and from the northern part into the Arctic ocean. The Peace is the only river navigable for steamboats.

The hills have a general northwest-southeast trend, following the strike of the formations and forming pronounced strike ridges. The major streams rise in the mountains and cut across the ridges, whereas the minor streams flow in valleys parallel to them. The region as a whole is well drained, although there are various large and small pre-glacial valleys which have remained dammed, and are therefore covered with swamps or lakes.

STRATIGRAPHY

The rocks of the area under discussion range in age from late Palæozoic to Upper Cretaceous. The surface rocks are largely of Cretaceous age, but the older ones are of interest because of their oil and gas prospects.

In the foothills belt, the section is seldom exposed below the Kootenay, and in only the major mountain uplift, or some offshoot from it, is the section exposed down to the Carboniferous. Thus the only information regarding the older formations in the foothills belt is obtained from deep well borings.

The Fernie and older rocks attain their maximum thickness in the mountain area, and thin eastward. In the Plains proper, it appears that the Lower Cretaceous rests directly on limestone, considered in most cases to be of Devonian age. Just where these intervening formations disappear to the east is not known, but from the deep drilling done in Turner valley, they appear to extend beyond the eastern limits of the foothills belt.

A generalized table of the formations found in the central part of the area is as follows:

Table of Formations*

System	Series	Formation	Character and Thickness
Cretaceous....	Upper Cretaceous...	Edmonton....	Soft irregularly bedded shale and sandstone, with coal at base.
		Belly River...	Grey fine grained conglomeratic and pebbly sandstones and greenish-grey shale; 2,000-4,000 feet.
		Benton.....	Dark grey to black marine shales and sandy shales, with limestone concretions; 2,000-3,000 feet.
		Blairmore.....	Grey and greenish-grey sandstones, sandy shales and sandstones; 600-1,500 feet.
	Lower Cretaceous...	Kootenay.....	Grey sandstones, grey to dark grey shales and sandy shales and coal beds; 400-600 feet.
Jurassic.....	.....	Fernie.....	Dark marine shales and sandstones; 550-1,500 feet.
Triassic.....	.....	Upper Banff shale.....	Dark grey to black argillaceous limestone and dolomite and calcareous shale, conspicuously banded; 3,400 feet.
Carboniferous.	Pennsylvanian....	Rocky Mt'n quartzite...	Grey siliceous dolomite and beds of quartzite; 700 feet.
	Mississippian.	Upper Banff limestone...	Massive light to dark grey limestone, in places cherty; 2,400 feet.
		Lower Banff shale.....	Brown calcareous shale and argillaceous limestone; 1,400 feet.

*The section below the Cretaceous was made by Dr. Warren on the Bow river west of Calgary and was furnished the writer by Prof. John A. Allan of the University of Alberta.

GEOLOGICAL HISTORY

The formations from the lowest Carboniferous up to and including the Triassic Fernie shales are largely, if not entirely, marine in this area. The Cretaceous was inaugurated by an uplift to the westward, causing the retreat of the sea from the foothills area, and leading to the formation of thick continental and lacustrine deposits of the Kootenay and Blairmore formations. Of these, the lower contains extensive deposits of coal, both in the foothills and in the intermontaine valleys of the eastern range of the Rockies. These formations are wedge-shaped and thin rapidly from the west to the east, a feature which is particularly true of the Blairmore.

At the end of Blairmore time, this area was depressed and the sea again entered it, leading to the widespread deposition of the dark marine shales of the Benton formation. In the foothills belt, this formation has a thickness of 2,500 to 3,000 feet, or possibly more in the northern part of the area.

Whether the down-warping of this area did not keep pace with deposition, or whether the land immediately to the west was uplifted slightly, is not known, but the end of the Benton was marked by the withdrawal eastward of the sea and the deposition in this area of continental deposits called the Belly River formation. The withdrawal of the sea appears to have been somewhat later towards the north end of the area, causing marine shales there to represent the time equivalent of the lower beds of the Belly River to the south. The sea did not retreat far, as shown by the interfingering of marine and continental deposits. The most widespread of these later marine invasions is represented by marine beds called Bearpaw shale that come at the top of the Belly River formation. The maximum extension of the Bearpaw sea brought it into the southern edge of the foothills belt.

The gradual retreat of the sea left extensive swamps to the east, and the elevation of the land to the west caused a resumption of essentially the same conditions that prevailed during the deposition of the Belly River formations. The Edmonton formation was thus formed, marking the top of the Cretaceous.

The same conditions prevailed during early Tertiary time, leading to the formation of thick deposits of shale and sandstone. These conditions were terminated in Eocene time by the great orogenic movement which caused the uplifting of the Rocky mountains, the folding and faulting of the foothills belt, and the gentle warping of the Plains area.

In the foothills, it appears that the formations from the lowest Carboniferous up through the latest Cretaceous are essentially conformable structurally, in spite of the slight movements that caused the successive retreats and incursions of the sea.

STRUCTURE

All the rocks of the area were laid down in horizontal or nearly horizontal beds. The extensive crustal disturbance accompanying the uplift of the Rocky mountains has caused the rocks of the foothills belt to dip at varying angles up to 90 degrees, with their inclination mainly to the west.

This condition was produced by the uplifting of the region, the pressure from the west which caused the rocks to break along numerous parallel, roughly north-south lines, and the formations on the west of these breaks overriding those on the east. Viewed broadly, the structure of the foothills is a miniature of that of the outer ranges of the Rockies. The outer range itself is up-thrust and shoved eastward at many places for miles, causing rocks of the mountains, ranging in age from pre-Cambrian to Carboniferous, to override and rest on Cretaceous rocks. In a less extensive way, this condition is repeated many times in the foothills belt, where the lower formations of the Cretaceous override the younger.

The dominant features of the structure of this area are overthrust faults. The pressure, which was most intense near the mountain front, was gradually absorbed and relieved eastward so that the faults and attendant folds become progressively less intense in that direction. The most easterly fault or fold is generally strongly developed, however, and is of particular interest because it usually offers more favourable prospects for oil and gas development than the others.

In a highly disturbed area such as this, many types of structure are naturally present. The faults follow closely the trend of the outer range of mountains, as do the folds. Prac-

tically all the faults are of the thrust or reverse type, and their planes dip westward. Accompanying the faults are folds of various types and sizes. Some broad open folds are present, but generally they are sharply overturned and asymmetrical in form. A generalized section which is typical of the area is shown in Figure 3.

The folds and faults have, in general, great lateral extension, some of them being traceable continuously for as much as 100 miles or even more. They are commonly found *en échelon*; where one dies out to the north another originates, offsetting it to the eastward and continuing in the same general direction. Space is not available to make more than brief reference to the types of folds and faults present. Only one structure, the Turner Valley anticline, will be described in some detail, because of its economic importance.

OIL AND GAS HORIZONS

In most of the early-developed oil fields of the Rocky Mountain district, oil was found in, or closely associated with, the Colorado shales (here called Benton) or their age equivalent, and most of the large fields are producing from these horizons. More recently, deeper drilling and the drilling of more deeply eroded structures have led to the discovery of oil in lower horizons. Oil has been found in the Dakota, of Lower Cretaceous age, and in the Sundance, of Jurassic age, in the Salt Creek field; in the Chugwater of Triassic, and the Embar of Permian, age in the Lander field; in the Ellis, of Jurassic age, in the Sunburst field in Northern Montana; and in the Madison, of Lower Carboniferous age, in the Soap Creek field, also in Montana.

It will be seen, therefore, that oil in the Rocky Mountain region has a wide stratigraphic range, from the lower Carboniferous to the Upper Cretaceous. In the Canadian foothills, oil was looked for during the big excitement of 1914 in the Cretaceous, and many wells were drilled with formations of that age as the objective. Good showings were obtained, amounting at places to semi-commercial production in the foothills near Calgary, mainly in the Turner Valley field. Various wells have since been drilled in the southern part of the area, near Pincher Creek, and one well in the central part

Generalized Section From Tp. 18 Rge. 2, W. of 4th. West to Front Range of Rocky Mountains
(After Canadian Geological Survey Map No 1980)
Vertical and Horizontal Scale
0 1 2 3 4 5 6 7 8 9 10 Miles
Jurassic Carboniferous and Devonian
Kootenay and Blairmore
Benton
Belly River
Younger than Belly River
Mt. Armstrong
Barril Ck.
Cataract Ck.
Pekisko Ck
Stimson Ck.

Figure 3.—Cross-section of Turner Valley field.

at Coalspur, without encountering favourable showings. So far, it is doubtful if any of the wells of the foothills has produced sufficient oil from the Cretaceous to justify the cost of drilling. Why these formations, which are so petroliferous in Wyoming, are largely barren in Montana, and so barren in Canada that they are doubtfully productive on a commercial scale, even under favourable structural conditions, is not known (1). That they are less petroliferous is obvious from the general absence of oil seepages in the highly faulted areas, and the lack of favourable results in the numerous wells that have been drilled. That there is some oil in the Cretaceous of the Canadian foothills has already been demonstrated; but it remains to be proved that it is present in commercial quantities.

Drilling below the Cretaceous in the Turner Valley field has developed a highly productive horizon for gas and crude naphtha (a high-grade crude oil which seems to be characteristic of the field) in a dolomite formation below the Cretaceous. While no fossils have been found to prove the age of this dolomite, from its stratigraphic position it is believed to represent the Upper Banff shale of Triassic age (2). From drilling that has been done, it would appear that this formation will be productive over much of the Turner Valley anticline, and there is reason to hope that it will be productive on other foothills structures. Even deeper drilling may open up lower horizons in this same or lower formations.

FIXED CARBON RATIOS

In view of the importance of the dolomite production found in Turner valley, it may be advisable to digress slightly from the main theme of this article to search for an explanation of the unusual character of the oil found. It is believed that an explanation is found in the degree of alteration that the rocks have suffered and in the effects of this alteration on the contained oil.

It is well known that the variation in the quality of coals is dependent in a large measure on the degree of alteration

(1) Several wells drilled since this was written have found larger production in the Cretaceous and indicate the presence of two commercially productive horizons, one near the top of the Dakota, and the other at the base of the Kootenay, formation.

(2) Later work has suggested that this dolomite may be older, possibly of Mississippian age.

(the effects of heat and pressure) of the enclosing rocks; or, to state the case in a different way, that the quality of coals may be used as an index to the regional alteration of the country rocks. Thus, in the slightly consolidated, undisturbed deposits we may find beds of peat; in the more indurated and more disturbed beds, bituminous coals grading into anthracite; and finally, in the much indurated and highly disturbed beds which have been subjected to the severe effects of alteration, we may find graphite, the end product of the metamorphism of coal.

We would not expect to find oil indigenous to beds that contain peat, nor to beds that contain graphite. In other words, to generate oil and also to permit its retention in a formation, the rocks must be subjected to a certain amount of heat and pressure, incident to the consolidation of the beds and to the development of geological structure, but not to such an extent as to dissipate the oil so generated. The best index so far available, to indicate that the process has progressed far enough and yet not too far, is the carbonaceous matter in the rocks, or coal.

The progressive change in the quality of coals of the regular bituminous type due to heat and pressure causes a decrease in its volatile content and a corresponding increase in its fixed-carbon content. Thus, the quality of the different kinds of coals, or the degree of metamorphism undergone by them, may be expressed as the percentage of fixed carbon in the coals, figured on an ash-free basis; or as the fuel ratio — the ratio of volatile matter to fixed carbon.

In this connection, David White has shown that: "No commercially important oil fields have yet been discovered in any area where the fuel ratio of the coals, occurring in the formations in which oil is sought or in the overlying formations, exceeds 2.3. More observations and tests are necessary to fix more exactly the stage of regional alteration beyond which commercial oil pools, though formerly present, will not have survived, but it is probable that the limit falls, in general, slightly lower than the point at which coals of the ordinary bituminous type show a fuel ratio of 2.2 or 66 per cent fixed carbon" (1). In other words, the danger point appears to be at about 66 per cent fixed carbon, and is passed at 68 per cent.

(1) White, David; Mining & Metallurgy, No. 158, Sec. 21, pp. 4-5, 1920.

It has also been pointed out by White (1) that the gravity of the oil is controlled by the stage of regional alteration of the country rocks. Thus, in general, in passing from western to eastern Pennsylvania, one finds progressively higher grades of oils, the highest-grade oil being furthest east, where the beds have been most altered. Where the rocks have been altered to such an extent that the originally contained oil-pools have been lost, gas and shows of freakish light-gravity oil may be found. In this connection White says: "It is important that, in a new region under consideration as to oil possibilities, every precaution be taken to ascertain whether the alteration of the rocks, as indicated by the stage of carbonization of the carbonaceous deposits, has not gone so far as to preclude the survival of oil in commercial amounts. As I have shown in the papers already cited, drilling in regions of greater metamorphism will find only gas or mere showings of 'white oil' — approximately kerosene — generally little more than samples, and nowhere in commercial amount. This principle appears to be proved by thousands of tests in the Appalachian field, in the mid-continent region, and in other parts of the world" (2).

It will be understood that the older rocks are not necessarily more altered than the more recent ones, the amount of alteration being dependent on the heat and pressure due to superimposed beds, or to dynamic stresses incident to folding and faulting. However, it is true, in general, that the older beds, having had a longer history, have been more altered.

The coals of the foothills belt are found largely in the Edmonton, Belly River, and Kootenay formations of Cretaceous age.

A study of the coals of the Edmonton formation shows that they range in fixed carbon, figured on an ash-free and moisture-free basis, from 49 to 61 per cent, or possibly 64 per cent, and average about 57 per cent. This variation is due in part to essential differences in the coals, and in part to the methods of analysis. It is apparent, however, that in none of these coals has the regional alteration progressed beyond the point at which a normal grade of oil, if any, would be found.

(1) White, David; Jour. Wash. Acad. Sci., No. 6, 1915.
(2) White, David; Mining & Metallurgy No. 158, Sec. 21, p. 5, Feb., 1920.

This formation outcrops mainly in the plains and along the eastern edge of the foothills, where the structural conditions are not commonly favourable and where the prospective horizons are very deep.

The coals of the Belly River formation show a fixed-carbon content ranging from 57 to 75 per cent, and averaging about 62 per cent. In the foothills belt, the fixed carbon is high and indicates that the borderland between the areas where normal grades of oil may be, and may not be, expected has been reached.

The coals of the Kootenay formation have a fixed-carbon content with an extreme range from 60 to 90 per cent. Throughout most of the foothills and all the mountainous area where this formation outcrops, its coals show too high a fixed-carbon content to permit the occurrence of normal crude, according to White's theory.

As the big production is coming from the dolomite which is much older and underlies the Kootenay, it is in conformity with this theory that an abnormal grade of crude should be found.

It has been the opinion of the writer that the high-gravity naphtha of this field is the characteristic and only crude that will be found there in this lower horizon.

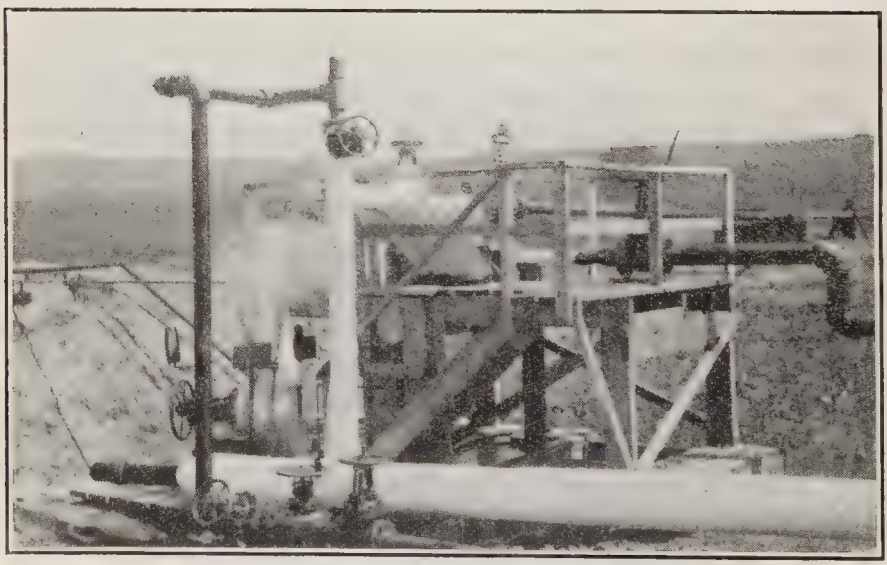

Figure 4.—Royalite No. 4 Well, Turner Valley, Alta.

TURNER VALLEY FIELD

The Turner Valley field is the only field in the foothills that has been developed on a commercial basis. A large number of wells were drilled there in 1913-14, some of which found oil and gas. The production, however, was small, and the field remained a doubtful commercial success until October, 1924, when the big Royalite No. 4 well was completed. This well came-in with a production of approximately 20,000,000 cubic feet of gas and 550 barrels of 73° crude naphtha per day, and has produced at about the same rate until the present.

The volume of gas produced by this well in the past two years has amounted to about 15 billion cubic feet, calculated on standard conditions of temperature and pressure. This is sufficient to have drained a porous formation 100 feet thick with 20 per cent pore space over an area of 85 acres, on the assumption that the gas existed in the rock under a pressure of 3,000 pounds per square inch.

During the past year, three additional wells have been completed, yielding a similar product but in smaller quantities. The producing wells may be summarized as follows:

Name of well	Daily gas production (cubic feet)	Daily naphtha production (barrels)
Royalite No. 4	20,000,000	550
Vulcan No. 1	7,000,000	120
Illinois-Alberta No. 1	4,000,000	65
McLeod No. 2	8,000,000	140
Total	39,000,000	875

The Turner Valley structure is a complex anticline about 15 miles long, trending north-northwest and located 40 miles southwest of Calgary. It represents the outer main anticline in this part of the foothills belt and covers parts of townships 19 and 20 North, Ranges 2 and 3, west of the 5th meridian.

The apex of the structure follows a valley in which Benton shales are exposed. On each side of this valley are pronounced strike-ridges of Belly River sandstones, forming the flanks and

Figure 5.—Royalite Oil Co's. Gasoline and Scrubbing Plant, Turner Valley.

dipping in opposing directions from 45 to 70 degrees. While the dips on the two flanks are nearly the same, they are slightly steeper on the eastern than on the western flank. Two streams cross the structure, one near the middle and the other near the north end. The exposures are few along the northern stream but abundant along the southern.

Along the latter, called Sheep creek, the exposures indicate the presence of a syncline on what would normally be the crest of the structure. This condition was recognized but not taken seriously by the geologists who studied the area because of the broken and contorted condition of the shale and the lack of any definite evidence as to how deep the syncline might be. Recent drilling, however, has proved that this syncline is an important feature of the structure, causing the wells located along the centre of the valley, where one would have expected the minimum depth to the underlying formations, to be 1,400 feet or more deeper than those immediately to the east and the west. Thus the Royalite No. 4 well, on the eastern side of the valley, encountered the top of the dolomite formation at 3,430 feet and the Illinois-Alberta well, on its west side, at 3,660 feet, whereas the Vulcan well, in the middle of the valley, found the dolomite at 4,862 feet. The structure appears to be a large, strongly developed anticline with a deep, narrow syncline along what would normally be the axis, thus giving the structure two minor axes, one on each side of a syncline.

This condition, while rare in the foothills, is not unique, as similar structures have been observed at other localities.

The structure plunges both to the north and south, becoming arched over by the Belly River formation, making the dolomite horizon too deep to be easily reached with the drill.

About midway between the two streams that cross the structure, it is cut by a transverse fault which appears to have its down-throw on the north side. This fault is believed to be a relatively minor feature, structurally, although it may have a pronounced effect on the accumulation of oil and gas. North of this transverse fault, the east limb of the structure is complicated by a strike-fault which follows the contact between the Benton shale and the Belly River formation. This appears

to be a thrust fault, with the Benton over-riding the Belly River. What the attitude of the underlying formations is in this northern part of the structure can only be determined by drilling.

PROBLEMS AND PROSPECTS OF THE FOOTHILLS

The highly folded and faulted condition of the rocks, the absence of good outcrops over large areas, and the difficulty of reconstructing the underground relations from surface observations, make exploration and development in the foothills both difficult and costly.

Throughout most of the belt, the general structural and stratigraphic relations can readily be deciphered, but the details of the structure which are necessary for the location of a successful test are generally obscure and uncertain. The steep dips of the rocks, and the alternation of hard and soft beds, makes drilling difficult and costly. With the progress of drilling the uncertainties are being lessened, and the difficulties are being overcome.

As described above, the structure of the foothills is characterized by both faulting and folding, but the former dominates. This being the case, unbroken anticlines are rare and fault blocks are common. So far no production has been developed on fault blocks, although it may be added that none of these have been adequately tested. The most promising structures are, obviously, well developed anticlines which are not so badly faulted that they do not have adequate collecting areas, and which are deeply enough eroded to make the prospective horizons within reach of the drill. Such structures are relatively rare in the foothills, but these conditions are most nearly fulfilled in the most easterly fold, where it has been eroded to the Benton shale, especially in view of the production now being sought in the dolomite horizon. From a study of the various structures of the foothills, it appears that the Turner Valley anticline fulfills the requirements equally as well as, if not better than, any so far found. Other structures to the north and south may be found to be as favourable, but this can determined only by drilling.

OIL PROSPECTS OF BRITISH COLUMBIA*

By G. S. Hume (*Member, C. Inst. M. & M.*)**

Drilling for oil and gas has been carried on in three areas in British Columbia, namely, western Peace River, Fraser River Delta, and the Flathead River Valley, Kootenay district. The western Peace River area lies within the Foothills belt and is not considered here.

Fraser River Delta

Complete information regarding prospects in the Fraser River area is contained in a report by W. A. Johnston (1). This report is the basis of the following summary. The lowland of the Fraser embraces, according to Johnston, the recent delta of Fraser river, which enters the strait of Georgia southwest of New Westminster, and extensive alluvial flats bordering the river above New Westminster. Underlying the Recent and Glacial materials in the Fraser River valley is a series of nonmarine Tertiary sediments with a maximum thickness of more than 4,500 feet. These sediments are alternating sands and shales, with some conglomerates, and thin seams and lenses of lignite, and they are mostly of fresh-water origin. As has been pointed out, "the fact that no commercial accumulations of either [oil or gas] are found outside of marine beds, except where these accumulations have clearly come up from marine beds below, would point to the sea as the ultimate source of the organisms or raw materials from which these hydrocarbons were derived." It, therefore, appears unlikely that rocks capable of yielding commercial supplies of oil and gas occur in the Fraser River delta. However, as stated by Johnston, this may not entirely condemn the Fraser River delta as a possible oil and gas field, for "because of lateral variations. . . . . such as might be expected in alluvial and deltaic beds like those of the Fraser Delta region, the

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**Geological Survey of Canada.

(1) Johnston, W. A., "Geology of the Fraser River Delta Map-area"; Geol. Surv. of Canada, Mem. 135, 1923.

same geological horizons may be coal-bearing in the landward part and petroleum-bearing in the seaward part". Also, "the salt water struck in the Empire well at a depth of about 3,600 feet indicates that the beds penetrated below that depth are probably marine." Drilling has revealed a few small gas flows in the Tertiary starta, but according to Johnston "there is little or no definite evidence that they are oil-bearing, except possibly to some slight extent in the lower marine parts of the rock series."

In the northern part of the Fraser Delta area the structure is monoclinal, but the structure in the southern and central parts of the area is unknown. As has been pointed out, however, terrace structure may occur and be sufficient to allow any existing oil or gas to concentrate within favourable horizons; also, the coarser sand strata are known to be lens shaped, a condition quite favourable to accumulation. Thus the prospects of the Fraser Delta area seem to depend on the presence or absence of a source of petroleum within, or in contact with, the Tertiary beds. Since a study of the sediments as exposed, and as known from well records, shows little evidence of possible source rocks, the hope of finding oil or gas seems to depend on migration of these substances from source rocks to seaward of the area tested by drilling.

As rocks that might act as a source of petroleum are entirely unknown, the assumption of their presence with migration of oil and gas from them into the non-marine sediments of the Fraser Delta area does not give much encouragement for further drilling.

FLATHEAD RIVER VALLEY, SOUTHEASTERN BRITISH COLUMBIA

Seepages of oil have long been known in the Kootenay district, British Columbia, on Sage and Kish-e-neh-na creeks, tributaries of Flathead river. The Sage Creek seepages were first reported by Selwyn in 1891, and occur 10 to 12 miles up the creek from Flathead river in rocks regarded by Selwyn as of Cambrian age. The oil occurred in some abundance, and gas was escaping from joints and cracks in the rock at the time of discovery. In recent years drilling has been done on Sage creek by the Crow's Nest Oil and Gas Company, and

drill samples to a depth of 3,000 feet have been examined by the Borings Division of the Geological Survey (1). These indicate that at least the lower part of the well was drilled in the Lewis series of pre-Cambrian age. According to a statement in the report of the B.C. Minister of Mines, for 1903,

> "the place at which the oil is found is at the top of an anticlinal in the formation . . . . . the axis of the anticlinal crossing the creek in a northwest direction. From this point the beds dip up the creek to the northeast and also down the creek to the southwest. The beds can be traced dipping to the northeast for about three miles, at first at a very flat angle but gradually increasing until the dip reaches 35 degrees. At this point a fault occurs, with, to the east, a different dip to the rocks. Further up the creek this is followed by other faults. Hence it may be said that three miles above the 'springs' is the limit in that direction of this possible field of accumulation. To the southwest, that is towards the valley of the Flathead, the beds dip at a very flat angle, probably not exceeding 10 degrees and apparently flattening out, as they are lost to sight under the gravel and surface wash of the Flathead depression.
>
> "On Kish-e-neh-na creek, at a point where oil is reported, a similar anticlinal fold occurs, but with the axis running nearly northeast and southwest, or with the course of the creek, the beds dipping off at an angle to the northwest and southeast into the adjacent mountains."

It was suggested by Dawson (2) that the rocks from which the seepages issue may "possibly overlie, in some places, those of the Cretaceous series, by reason of overthrusts", and that the oil "may have originated in consequence of heat, at considerable depths in the earth's crust, acting upon the fixed hydrocarbons contained in the rocks of that series". As has been pointed out (3), however, "if this explanation is the correct one, the overthrust must have been very great indeed to bring

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(1) Ingall, E. D., "Deep Borings in British Columbia and the Yukon"; Geol. Surv. of Canada, Sum. Rept., 1924, pt. A, p. 146.

(2) Dawson, G. M., Geol. Surv. of Canada, Ann. Rept., 1898, p. 23A.

(3) Ann. Rept., B.C. Minister of Mines, 1903, p. 92.

the Cretaceous beds underneath the present oil seepage, as the Cambrian beds extend eastward from 12 to 15 miles from this point, in fact over the summit into Alberta". It is further pointed out that "the oil might have travelled westward underground for some distance, but this is not probable, as a few miles to the eastward of the point of occurrence of the oil there are several faults which have the appearance of being profound, and would, therefore, have allowed the gas and oil to rise to the surface through them, but of this there is no indication."

Detailed knowledge concerning the area in the vicinity of Sage and Kish-e-neh-na creeks is very limited, and the suggestion of Dawson that Cretaceous rocks underlie much older rocks as a result of overthrust has not been proved or disproved. To the east, at Waterton lake in Alberta, similar oil seepages occur, and it is fairly well established that in this area Cretaceous rocks are overlain by older rocks as a result of overthrust. In a well drilled near Waterton lake, according to Dowling (1), "there seems little doubt that the drill penetrated the dolomites of the Waterton formation and entered soft shales which seem to be Cretaceous. The zone of overthrust was apparently penetrated at about 1,500 feet, although at 1,900 feet and lower the beds were probably affected by crumpling and folding."

The Flathead River valley, to the west of Sage creek, has been studied by Mackenzie (2), who reports that the Kishinena formation considered to be of Eocene (?) age shows considerable bituminous content. Regarding the oil content, Mackenzie says:

> "a marked characteristic of these rocks is their bituminous odour when struck or rubbed, and on joint planes brownish stains are frequently seen which give a strong bituminous smell when heated..... some bands are impregnated more than others with the bitumen, which serves to darken

(1) Dowling, D. B., Geol. Surv. of Canada, Sum. Rept., 1920, pt. B, p. 20.

(2) Mackenzie, J. D., "Geology of a portion of the Flathead Coal Area, B.C."; Geol. Surv. of Canada, Mem. 87, 1916.

them..... Throughout all these rocks, and with varying concentrations in different specimens, are found impregnations of yellowish, brownish, and black material, which is thought to be a residue from the evaporation of petroleum. ..... In many cases the bitumen takes the form of spheres..... The spheres are thought to represent drops of petroleum that have segregated under the influence of surface tension in the water-saturated rocks, yet were unable to migrate to any considerable distance owing to the very dense character of the enclosing material."

In summing up the conditions regarding the petroleum prospects of this area, Mackenzie states:

"that bituminous material exists in the Kishinena rocks is without question, and its source may be with confidence assigned to the soft parts of the numerous mollusks with whose shells it is now so closely associated. Whether or not petroleum as such exists in these beds is not yet proved, and chloroform tests of some of them furnished only negative results. However the seepages of a kerosene-like oil on Sage creek, east of Flathead valley, suggests the rather unlikely possibility that the oil may have been derived by migration from these bituminous Tertiary sediments. The porous, coarse nature of many of the sands of the Kishinena formation would render them suitable for petroleum reservoirs, and although little is known of their structure in detail, it is probable that local conditions of porosity or succession of strata might afford a gathering place for bodies of oil, although these assuredly would not be large. The small possible thickness of oil-bearing strata and their position near the surface render the finding of any considerable body of oil improbable for, if any had been present, it would have readily escaped by natural channels and, furthermore, a sufficient gas pressure to make a field workable is unlikley at such shallow depths..... It is apparent that the chances of the occurrence of commercial deposits of petroleum in the Flathead map-area are very slight."

BITUMINOUS SANDS OF NORTHERN ALBERTA*
Their Character and Economic Importance

By S. C. Ells (*Member, C. Inst. M. & M.*)**

Introductory

The extensive areas of the Dominion lying beyond the zone of present permanent settlement are frequently referred to as 'Northern Canada'. For the most part, this territory is as yet somewhat remote from adequate rail transportation, though portions of it have been explored and even mapped in some detail. As regards other portions, however, the geography and actual economic possibilities are largely unknown. It is generally conceded that, throughout a large part of this territory, there is little scope for agricultural or lumbering activities. Broadly speaking, large development of much of Northern Canada will therefore depend on the discovery of important mineral deposits of commercial value.

The bituminous sands (1) in the Province of Alberta are an outstanding example of non-metallic deposits which have been examined by government engineers. Information at present available regarding this deposit is based almost entirely on results of an investigation initiated in 1913 by the Mines Branch, Dept. of Mines. As a pioneer effort toward mining development in Northern Canada, successful commercial exploitation of the deposit would constitute an achievement of first-rank importance. It is therefore of interest to consider certain physical features presented by this deposit, and to indicate those factors which will apparently govern suggested development.

General Character of the Area

The surface of the area underlain by bituminous sand may be described as a peneplain, much of which is covered by swamp and muskeg. Through the plain, the more important

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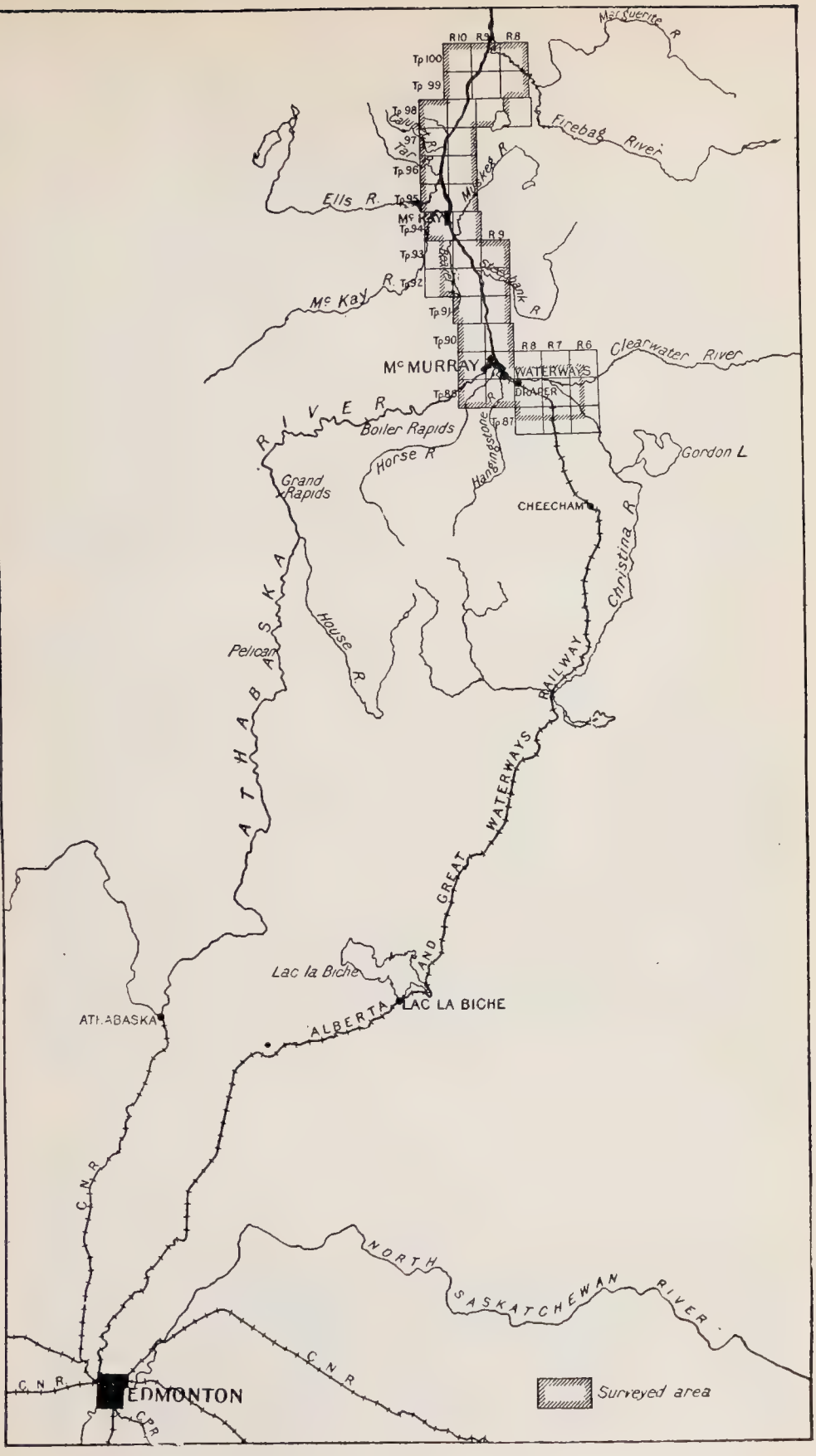
*Published with the permission of the Deputy Minister of Mines, Ottawa.

**Mining Engineer, Mines Branch, Department of Mines, Ottawa.

(1) S. C. Ells, Reports on Bituminous Sands of Northern Alberta, 1913-26; Mines Branch, Dept. of Mines.



Index map showing position of principal area underlain by bituminous sand.

Figure 6.

streams — excepting only Clearwater and Athabaska rivers — have cut narrow, notch-like valleys. Beyond the rim of these valleys, the ground rises gradually. Northeast and east from Athabaska valley, large areas of country are covered by sand and sandy soil derived from pre-Cambrian rocks to the east. In passing westward, clay soil predominates. With such a topography, outcrops of bituminous sand are thus confined to the slopes of older valleys and to cut banks along present water courses. As might be expected in a country covered by a heavy mantle of clay, and through which streams are deeply entrenched, slips in the banks constitute a notable topographic feature. Individual slides bring down, at times, many thousands of tons of clay and soil.

Where drainage has been effective — as in the relatively limited zones adjacent to drainage depressions — there has been a good growth of poplar, jack pine, and spruce. Unfortunately, a considerable percentage of such growth has been destroyed by fires, and large areas are now covered by dense second growth. Thus, although the total acreage of merchantable timber constitutes a considerable area, stands are scattered and individually of somewhat limited extent. Tables have been prepared for each township and range included within the areas surveyed, giving percentages of land and water areas, of muskeg, slough and swamp, of poplar, jack-pine, spruce and second growth, and of clay and sandy soil. In considering development in any area that may be selected, such tables furnish a general indication of surface conditions, soil, and forest growth.

CLIMATE

The climate in the McMurray area during spring, summer, and autumn, is not unlike that of central Alberta. Winter weather is dry and healthful, and very similar to that which prevails in the Cobalt and Porcupine mining districts of northern Ontario. The snowfall is relatively light. Reliable meteorological records have been kept at McMurray since 1920.

TRANSPORTATION AND COMMUNICATIONS

A standard-guage railway, known as the Alberta and Great Waterways railway, has been completed from Edmonton to McMurray, at the head of navigation on the Athabaska-Mackenzie system, a distance of approximately 300 miles. This railway is controlled by the Government of the Province of Alberta and is operated by a Commission. Adequate telegraphic and postal services are maintained. Beyond the northern terminus of the railway, stern-wheel steamers and large power boats, with ample accommodation for passengers and freight, provide transportation during summer months to all points between McMurray and the Arctic ocean, a distance of some 1,700 miles. Postal and wireless communications are maintained by the Dominion Government.

GEOLOGICAL HORIZON OF BITUMINOUS SAND DEPOSIT

It is not the writer's intention to discuss conditions which resulted in the formation of the deposit, nor the probable origin of the bituminous content. Geologically, however, the bituminous sand occurs at the base of the Cretaceous formation and directly, but unconformably, overlies limestones of Devonian age. Originally in the form of soft sandstones and uncompacted sands, subsequent and more or less complete impregnation by heavy asphaltic hydrocarbons has resulted in the present coherent material.

A brief reference to the geological section along the Athabaska river will furnish some indication of the general character of the overburden. Between Athabaska and the Cascade rapids, La Biche shales, Pelican sandstones and shales, Grand Rapids sandstones, and Clearwater shales are, at various points, well exposed; but northward and eastward from the Cascades rapids, the Clearwater series and surface drift appear to constitute the entire overburden above the bituminous sand. The surface drift consists chiefly of boulder clays and sand.

The sequence of formations is indicated in the following table:

Table of formations

Era	Period	Thickness in feet*	Formation
Quaternary	.....	.....	Gravel, sand, and clay.
		Unconformity	
Mesozoic	Cretaceous	1,100+	La Biche shales (grey and black shales with concretions).
		35	Pelican sandstone (cross-bedded sandstones and conglomerates.)
		90	Pelican shales (black shales with thin sandstone partings).
		280	Grand Rapids sandstone (sandstone with concretionary nodules).
		275	Clearwater shales (soft grey and black shales: grey and green sandstones).
		60-200	McMurray (bituminous sand).
		Unconformity	
Palæozoic	Devonian	700+	Limestone series.

*Thickness of formations based in part on measurements by F. H. McLearn, Geological Survey of Canada.

The general structure of the area between Athabaska and lake Athabaska is marked by dips of low angle. Between Athabaska and point Brule, there is a southwesterly dip of from 5 to 10 feet per mile; between point Brule and McMurray, the so-called Athabaska anticline is marked by dips of 3 to 4

feet per mile; to the north of McMurray dips are flat, and the general structure is indeterminate. General absence of rock exposures for many miles to the east and west of Athabaska river restricts detailed study of the general structure.

STRATIGRAPHY

The following references to stratigraphy are based on observations within the area mapped and examined by the writer. This area comprises townships 88-100, ranges 7-11 (inclusive), and embraces the greater part of the bituminous sand exposures.

Figure 7.—Devonian limestone overlain by bituminous sand.

Devonian.—Well records and exposed sections indicate that the Devonian consists chiefly of limestones, dolomites, and shales, with which are associated some anhydrite, gypsum, and rock salt. The character of the shales has not been accurately determined, but, where well exposed, the limestone comprises hard, highly fossiliferous bands alternating with easily eroded, rubbly, highly argillaceous strata. The main structure has been affected by minor folding, as a result of which the limestone rises and falls along Athabaska river in a long series of gentle anticlines. The general regional strike is apparently northwest and southeast.

Exposed sections are confined to Athabaska river and its principal tributary streams, and attain a maximum thickness — on Beaver river — of approximately 100 feet. It is clear that the upper beds were, in certain areas, subjected to severe erosion prior to deposition of the overlying Cretaceous sediments. This, together with absence of definite marker beds and the uncertainty regarding possible faulting, renders difficult the correlation of somewhat widely separated exposures. It also accounts for the variable exposed thickness of the bituminous sand itself.

Pockets of semi-liquid bitumen, some of which are apparently of considerable extent, are noted on logs of a number of wells drilled into or through the Devonian. There is as yet no definite evidence to indicate whether this bitumen has originated in Devonian strata, or has been derived as seepage from the overlying bituminous sand. The fact that certain of these pockets are reported at depths of more than 500 feet appears to indicate that the bitumen has originated *in situ* — probably from certain Devonian shales.

Cretaceous.—Bituminous sand — referred to as the McMurray formation — occurs near the base of the Cretaceous, and unconformably overlies the Devonian. In certain areas, beds of residual clays, apparently derived from the more argillaceous limestones, occur at the contact. Fossils secured by the writer and representing a fresh-water fauna have been identified by McLearn as follows:

Unio n. sp. (a very ornate shell).
Unio (?) n. sp. (a small smooth shell).
Campeloma n. sp.
Pachymelania n. sp.

EXTENT AND GENERAL DESCRIPTION OF DEPOSIT

During the past twenty years, many statements have appeared relative to the extent and probable economic importance of the McMurray deposit. Liberal estimates of area and of average thickness of bituminous sand have usually been accepted, and the calculated tonnage commercially available has been very large. In arriving at this conclusion,

three important factors have frequently been overlooked: (1) transportation; (2) variation in thickness and quality of bituminous sand, and (3) variation in thickness of overburden.

As regards transportation of a bulky, low-grade material, it is obvious that a large part of the area underlain by bituminous sand will, for a long period, remain quite inaccessible to development. Moreover, in many parts of the area, it has been found that the bituminous sand itself is of such a low grade as to be of little or no value. Lastly, and assuming that all excavation must take the form of open-cut work, overburden becomes a factor of dominant importance. Even taking these three factors into consideration, there still remains a large tonnage of bituminous sand commercially available.

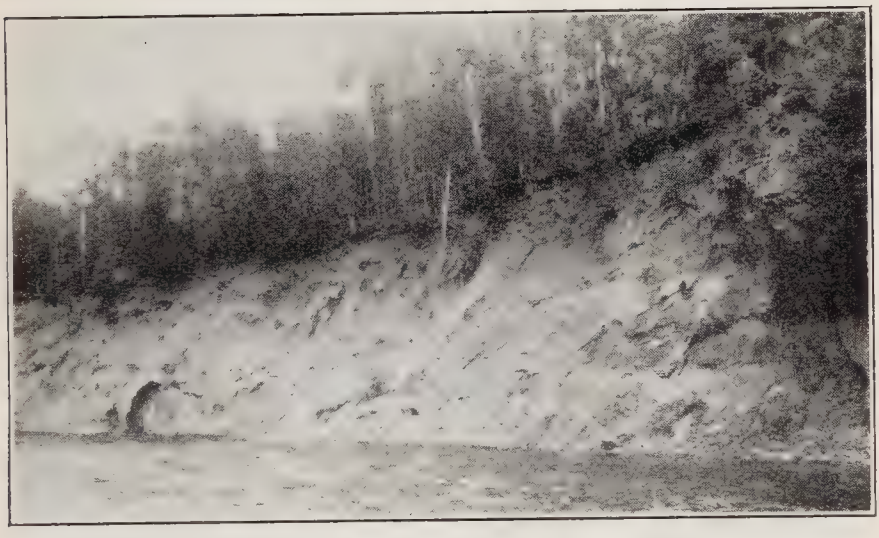


Figure 8.—Bituminous sand under thin, gravelly overburden.

It appears unnecessary, nor is it at present possible, to attempt a definite estimate of the area underlain by bituminous sand. The writer has measured and examined more than 300 individual outcrops, all of which represent portions of a practically continuous deposit. These outcrops extend along Athabaska river and its tributaries through a total distance of more than 260 miles. The direct distance in a north and south direction, through which outcrops have been noted, is approximately 115 miles, and that from east to west approximately

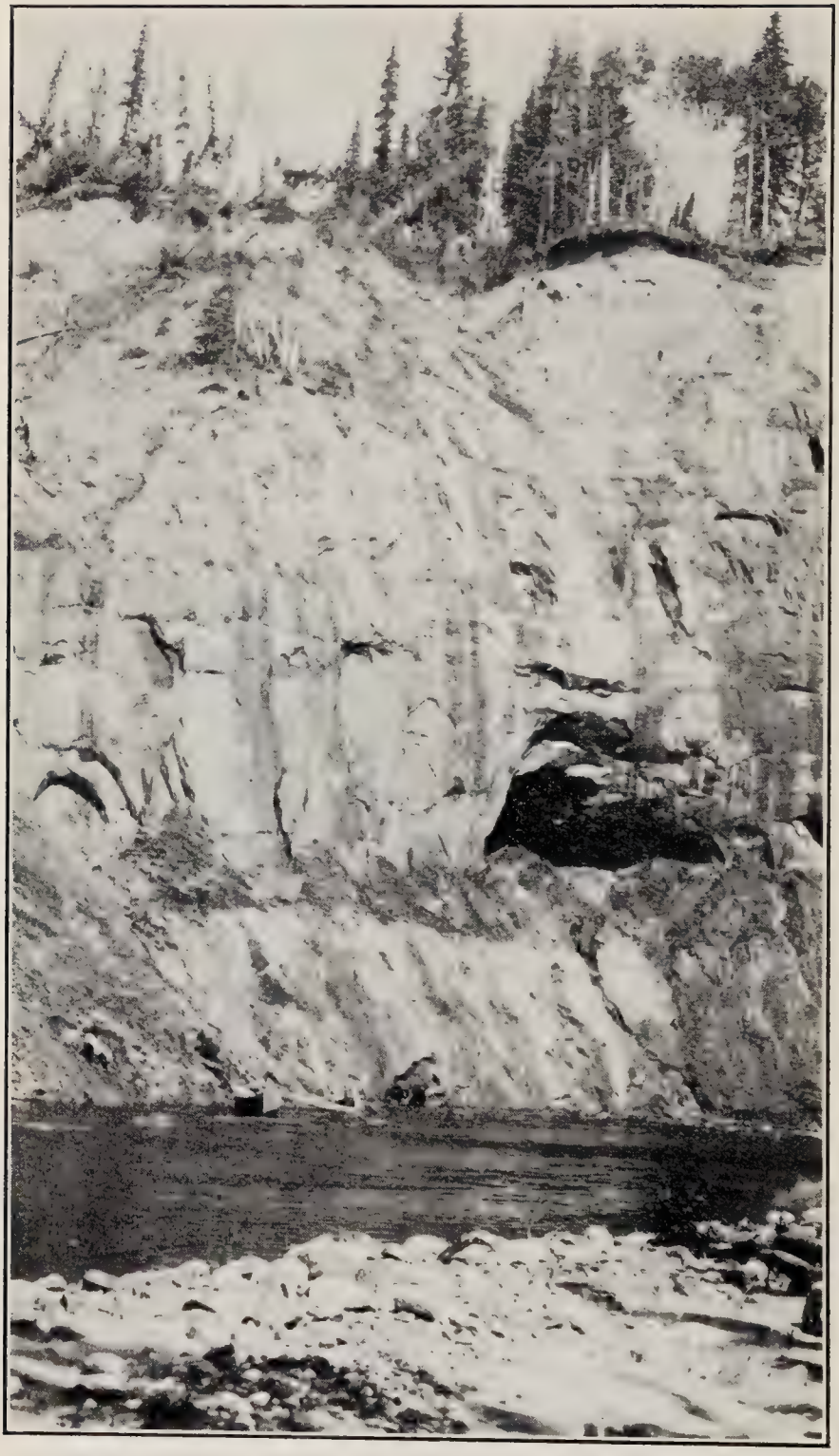


Figure 9.—Bituminous sand on Steepbank river. Illustrating massive structure.

55 miles. Possible extensions of the deposit under heavy overburden — particularly toward the south — probably materially increase the area indicated by the above measurements.

Towards its northern boundary, the main body of bituminous sand appears to terminate somewhat abruptly against modern lake deposits, in which bituminous sand has, to some extent, been redeposited in the form of numerous minor partings in Post Glacial deposits. Marginal deposits of this type indicate the approximate position of a portion of the southerly shore line of Glacial Lake Athabaska, and furnish an excellent opportunity for the study of a wide variety of such occurrences.

During the past 20 years, 36 wells have been drilled within the McMurray area. Although recorded logs of many of these wells are of doubtful value as accurate records, nevertheless they furnish information regarding general stratigraphical conditions. In no instance has free petroleum of commercial value been encountered.

It has been possible to definitely eliminate certain parts of the McMurray area from further consideration as regards present economic value, but, for reasons noted elsewhere, it is not at present an easy matter to definitely designate the areas which will prove of greatest commercial value. Mere measurements of what are, frequently, imperfectly exposed vertical sections cannot convey definite and reliable information, and, in many instances, they must prove misleading. Indeed, it is quite possible that certain portions of the deposit which are at present partially or wholly obscured, may, on examination, present advantages over certain other areas where outcrops are well exposed. For exposures naturally occur at bends of streams, where the current, impinging against the concave shore, has caused the formation of cut banks. So uniformly does this rule apply that, given an accurate map of any of the streams flowing through the area underlain by bituminous sand, it is possible to predict very closely those points at which outcrops of bituminous sand will be found.

Surface indications may also prove misleading as regards the character of the bituminous sand itself. Thus, for example, a coarse-grained aggregate weathers out much more rapidly

Figure 10.—Fossiliferous strata associated with bituminous sand (McMurray formation).

than a fine aggregate, and an outcrop that appears low in bitumen content may rapidly improve in quality, even at shallow depth. In other instances, owing to the gradual down-flow of bituminous sand from high-grade bands, very considerable thicknesses of low-grade material, heavy beds of inter-stratified clay, and the underlying limestone itself, may become wholly obscured. Indeed, only after detailed exploration, by means of adequate equipment, can the true value of any area be finally determined.

The lower limit of the bituminous sand, where exposed, is well defined by its contact with the Devonian limestone. There is not, however, any well defined upper limit. In the majority of well exposed sections, the richer material occurs in the lower part, shading off into leaner grades. In passing upward, narrow bands of sandstones, clay ironstones, clays, and lignites, gradually increase until, by their preponderance, they entirely replace the bituminous sand itself. Along the upper surface of such impure partings, bitumen tends to collect, forming zones of greater enrichment. Consequently, such partings in beds of otherwise rich bituminous sand may frequently be recognized during warm weather by horizontal lines of seepage.

A bituminous sand adapted to paving requirements should possess uniformity in grading of mineral aggregate and in percentage of a suitable associated bitumen. In a body of siliceous sand of such wide areal extent as that under consideration, variation in the grading and purity of the mineral aggregate must be expected, and does exist. Moreover, to some extent the degree of impregnation has depended on the grading of the sand. The medium and moderately compact deposit is usually the richest, whereas the finer aggregates have apparently somewhat retarded complete saturation. At the time of impregnation of the sands, coarser aggregates would probably retain the greater part of the oil, while water would fill pore spaces or voids in the finer aggregates.

Thus the percentage of associated bitumen varies widely in many exposed sections examined. In a large number of outcrops, however, a bed of bituminous sand of commercial dimensions, with a sufficiently uniform impregnation of

bitumen, was found. Indeed, it is probable that lack of uniformity in the percentage of bitumen present in any particular bed selected will be one of the least serious difficulties to be overcome.

Figure 11.—Typical Grand Rapids sandstone showing large spherical concretions.

Where overburden is light, low-grade outcrops are characterized by a distinctive type of erosion. Along the upper edge of the bituminized strata, sharply defined notch-like gullies, accompanied at times by roughly vertical fissures, occur at frequent intervals in the friable and loosely compacted material. When the lower strata of such exposures consist of high-grade material, the indentations do not extend downward into it. So typical is this form of weathering, that, with experience, it is possible to recognize low-grade and worthless exposures by this indication alone. Talus piles may also be considered as a general indication of the general character of adjacent exposures. Where such piles remain loose and uncompacted, the outcrops from which the material is derived are usually of low grade; where talus piles become cemented together to form a compact mass, the adjacent outcrops are usually composed of rich material.

To some extent, percentage of associated bitumen and prevalence of impure partings may be recognized in the weathering of an exposed section. Beds of high-grade homo-

geneous sand are usually marked by a typical conchoidal cleavage roughly parallel to the face. As the percentage of contained bitumen becomes lower, the cleavage is more and more angular.

Until quite recently, knowledge of the character of bituminous sand has been based entirely on an examination of samples secured by core drilling of actual outcrops by standard asphalt augurs. Surface sampling by means of shallow trenches has been avoided, since it is obvious that such sampling can only prove misleading. In 1924, however, a limited amount of shafting was undertaken at points somewhat removed from weathered exposures. Regarding the character of bituminous sand passed through and the conditions encountered, certain features may be briefly noted.

(*a*) *Movement due to pressure.*—Within and adjacent to stream valleys, bituminous sand has been affected in marked degree by pressure of overburden. Such pressure has caused slipping, varying in intensity with topographical conditions and with weight of overburden. In places, the bituminous sand has become laminated to such an extent as to resemble a thinly bedded shale.

(*b*) *Sulphur.*—Sulphur occurs either in the form of white sulphur compounds, deposited along slip planes and probably derived from impregnated swamp water, or as nodules of iron pyrite segregated as thin beds or lenses. Obviously, where sulphur is deposited in the bituminous sand by circulating waters, the amount present will vary according to the extent of slipping that has taken place. This, in turn, will depend on topographical conditions and will be at a minimum in those areas in which overburden is relatively light.

(*c*) *Local enrichment near outcrops.*—From a comparison of samples secured by shafting and by boring at a depth of approximately 3 feet inside nearby outcrops, it appears that a local zone of enrichment has been formed adjacent to exposures. This is probably due to a gradual gravitation of bitumen toward an oxidized and partially sealed face. The depth to which alteration has extended will be governed, to some extent, by angle of slope of outcrop.

Figure 12.—Section of typical marginal deposit, showing thin, interbedded bituminous sand partings.

(*d*) *Instability of fresh bituminous sand.*—The writer has always maintained that excavation of bituminous sand by underground mining methods is not commercially feasible. Experience in timbered shafts here referred to, substantiates this view. When excavation has disturbed the equilibrium of the bituminous sand, movement within the mass results, more especially where water seeps have increased the tendency to caving. Moreover, there is no solid rock strata to which timbering can be secured, and props, even when set on a broad base of heavy plank, rapidly settle.

(*e*) *Stickiness.*—Prior to 1924, all excavations by the writer had been made at outcrops along the banks of streams where weathering had affected the character of the bituminous sand. Under such condition, it was found necessary either to use heated spades or to clean such tools at frequent intervals. In excavating unaltered bituminous sand, it was rarely necessary to clean the cutting tools. This may probably be attributed to higher moisture content of the bituminous sand, and to the somewhat lighter character of the associated bitumen. In considering the use of mechanical equipment in connection with mining operations, gumming-up of cutting blades or dippers had previously been considered as unavoidable.

(*f*) *Seepage of hydrocarbons.*—In shafting through bituminous-sand strata, walls of shafts, and pools of standing water, became covered with a thin film of dark brown bitumen after a lapse of four to six hours. At but one point a small seepage of dark green petroleum was observed, and in no instance were seepages of sufficient extent to permit of even small samples being secured.

From information obtained, it appears that, in the McMurray area, recovery of hydrocarbons by drainage into galleries is not practicable. This conclusion is confirmed by a comparison of the viscosity of bitumen extracted from Pechelbronn bituminous sand, and of petroleum derived by natural seepage from Pechelbronn bituminous sand, with that of bitumen separated from both weathered and unaltered bituminous sand from the McMurray area.

It is evident that, at many points over a wide area, large tonnage of good bituminous sand can be found. In almost every instance, certain conditions are favourable, while others

are unfavourable. It is only by carefully estimating relative advantages and disadvantages in each individual sub-area that an intelligent selection can be made. From a topographical standpoint, triangular areas situated at the junction of two stream valleys, 'hogs backs' and terraces, offer distinct advantages for removal and disposal of overburden. Moreover, sub-areas that are entirely favourable for commercial development on a comparatively small scale, as, for example, when bituminous sand is to be excavated for paving purposes, might be of little value if distillation, with recovery of crude petroleum on a large scale, were contemplated.

It will thus be seen that throughout the area there is marked variation in conditions which will affect commercial development, notably as regards shipping and transportation facilities, variation in thickness and quality of bituminous sand and of overburden, and in topographical conditions which will determine selection of plant sites, waste disposal sites, town sites, water supply, etc.

For many years, the occurrence of so-called 'tar springs', or seepages, of bitumen has been recognized throughout the area under discussion. The writer is familiar with upwards of 40 such springs, but in no instance are they in themselves of commercial value as a source of bitumen. They have, at times, been regarded erroneously as a definite indication of the presence of petroleum pools. Instead of coming from below, however, the bitumen merely seeps laterally from slightly inclined beds of particularly rich, coarse-grained sand. An underlying impervious clay parting, together with a small local depression, makes possible the formation of a small pool of bitumen.

As previously indicated, available information relative to the Alberta deposit of bituminous sand is based largely on investigations by the Mines Branch during the period 1913-26. In part, the results and scope of this investigation may be briefly summarized as follows:

Sampling and analyses:

A large number of core and other representative samples have been analyzed, and the physical and chemical characteristics of the associated bitumen determined. Results indicate

that the content in bitumen ranges up to a maximum of over 20 per cent, and that a very large tonnage of bituminous sand possesses an average content of not less than 15 per cent.

Surveys:

Detailed topographical maps of areas aggregating some 1,250 square miles adjacent to Athabaska river and its tributaries, have been completed. These maps were originally drawn on a scale of one inch to 1,000 feet, but have been published on a scale of one inch to one-half mile. Using as a base upwards of 600 miles of profiles, 40 east-west sections have been prepared. On these, projected relative thickness of overburden and of bituminous sand illustrate in a general way those portions of the McMurray area in which conditions appear favourable for development. A key map has also been prepared, on which all outcrops are classified according to their apparent relative value.

Shafting:

Results obtained in connection with shaft sinking are summarized in preceding paragraphs.

Core drilling:

The necessity of accurate and systematic prospecting as a preliminary to actual development has long been recognized. Consequently, during the past two seasons, an effort has been made to demonstrate in the field an efficient type of core drill which will furnish accurate samples of overburden and of underlying bituminous sand. Results of this feature of the Mines Branch investigation will be made public shortly.

Demonstration paving, and preparation of asphalt mastic:

In the United States, the early use of natural rock-asphalt in the construction of various types of wearing surfaces was handicapped and retarded through the use of inapplicable methods and faulty manipulation. Moreover, persistent and hostile criticism had been directed against the proposed use of Alberta bituminous sand as a paving material. It, therefore, appeared desirable that one or more demonstration surfaces be constructed.

In 1915, three types of wearing surface — including bitulithic, bituminous concrete, and sheet asphalt — in which the cementing medium consisted wholly of Alberta bituminous sand, were constructed. The success which attended this first attempt is indicated by the following letter, received in February, 1925, from Mr. A. W. Haddow, City Engineer, Edmonton:

> "With regard to experimental paving on 82nd Street, which was laid by you in 1915, I am glad to advise you that this has remained in excellent condition, and seems to be good for many years of satisfactory service."

The radius of distribution for crude bituminous sand for paving purposes will be controlled in part by freight rates, and to a lesser extent by cost of local supplies of suitable aggregates. Should it eventually be found possible to secure a sand-gravel freight classification, radius of distribution may be extended to include centres of population as far east as the city of Winnipeg.

A number of samples of asphalt mastic, in which Alberta bituminous sand and local limestone dust are the principal constituents, have also been prepared. Preliminary results appear to indicate that a satisfactory product can be produced by the use of these materials.

Shipments of crude bituminous sand:

A number of carloads of bituminous sand have been mined and shipped by the writer to various points in Canada, the United States, and Europe. This material has been utilized in connection with investigations undertaken by private individuals and companies.

Recovery of hydrocarbons from crude bituminous sand:

The problem of recovery of solid, semi-solid, and liquid hydrocarbons from crude bituminous sand, by mechanical separation and by distillation, has been studied in the laboratory. This study has included separation by means of heated water, with and without the addition of reagents, and at temperatures (under pressure) up to 325°F.; separation by

flotation methods; and separation by use of centrifugal apparatus. Final purification has been attempted by the use of centrifuges, filter presses, and settling tanks. Dry distillation of the bituminous sand has been carried out, and the crude petroleum produced has been fractioned and refined. Results of this work have been encouraging, but inconclusive. Data and information relative to a large number of processes designed by private individuals have also been compiled.

From a consideration of the general trend of invention in this field, processes for recovery of hydrocarbons from bituminous sand may be grouped into three general classes.

(1) Separation of associated bitumen through the washing action of heated water, with or without the addition of reagents. Mechanically, preliminary separation by such methods is entirely feasible. Apparently the principal difficulty consists in removing water, and the finer sand particles and silt, during final purification.

(2) Separation of associated bitumen through the leaching action of certain solvents, such as petroleum distillates. Such separation is more rapidly effected and gives a cleaner product. Subsequent recovery of the low-boiling solvents used presents fewer difficulties than the removal of water and silt.

(3) Recovery of associated hydrocarbons by heat distillation. Such recovery implies the use of higher temperatures, and results in the production of varying percentages of unsaturated compounds. Subsequent recovery of heat from a large mass of inert waste sand apparently constitutes one of the chief problems.

As a mechanical problem, recovery of hydrocarbons from bituminous sand is entirely feasible by each of the above general methods. As a commercial problem, such recovery is largely a question of supply and demand. As in the case of oil shales, commercial development will be possible when, for any reason, the cost of well petroleum and its derivatives reaches a point approximating the cost of production of hydrocarbons from bituminous sand. Such development implies adequate financial resources, and should not be undertaken by men of small capital or by those who desire quick returns on their

investment. Meanwhile, it appears that much duplication of effort exists, and that greater co-operation is desirable between government and private investigators, and among the latter themselves.

Removal of overburden, and mining:

In the past, the limited tonnage of bituminous sand excavated by the writer has not warranted the installation of labour-saving mechanical equipment. Overburden has been removed by the use of manual tools, and the bituminous sand itself broken down by the use of a slow explosive. On the other hand, should commercial development of the McMurray deposit be undertaken, it appears that financial success will depend on a comparatively small profit per ton magnified by large tonnage. Such a condition will imply economy in operation and the introduction of highly efficient excavating equipment.

During recent years, methods adapted to large-scale stripping and mining operations have reached a high state of development. Only specialists thoroughly familiar with the most recent practice are competent to express an opinion regarding procedure best adapted to individual problems. The writer has, however, discussed the problem of the McMurray deposit with leading equipment manufacturers and others, and has considered relative merits of hydraulicing, various types of dragline machines and shovels, link belt excavators, and shale planers. As a result, choice of equipment has been narrowed down, but final decision will depend on practical experience. Meanwhile, the writer considers that the use of a modified form of shale planer will have distinct advantages in excavating bituminous sand.

Economic considerations:

In considering the economic problem presented by the Alberta deposit of bituminous sand, three outstanding features may be noted:

(1) The deposit represents the largest known body of solid asphaltic material.

(2) The deposit is, as yet, commercially undeveloped.

(3) At the present time, practically all asphaltic materials used in Canada are imported from foreign countries.

There are three lines along which commercial development may be attempted. These are:

(1) Use of the bituminous sand in a more or less crude form as a wearing surface for streets and highways, and as a basis for the manufacture of asphalt mastic.

(2) Various commercial applications for the bitumen when separated from the associated sand aggregate.

(3) Destructive distillation of the crude bituminous sand or partially purified bitumen, with recovery of various liquid hydrocarbons.

It is obvious that proposed commercial development of the Alberta deposit of bituminous sand must take into consideration the following general factors: assurance that ample supplies of suitable raw material are available; that mining and other plant equipment can be secured and installed at reasonable cost; that labour is available at reasonable rates and can be retained under local conditions; that products can be disposed of (and competition successfully met) at remunerative prices and without involving undue storage charges owing to seasonal demand.

Reduction in weight and bulk of finished products will be reflected in reduced freight costs and in extended radius of distribution. Development of bituminous sand at points somewhat removed from present rail transport will introduce the problem of additional transportation by water, pipe line, or railway, and only large and assured production will warrant the necessary capital expenditure to provide such facilities. Consequently, for the immediate present, effort should be directed toward determining, by core drilling, the true value of those areas which are adjacent to existing rail transportation.

The writer considers that, from the view point of really large-scale development, the Alberta deposit should be regarded primarily as a possible source of liquid hydrocarbons. It should also be regarded as an important potential source of solid and semi-solid bitumen, and of crude bituminous sand

adapted for various types of wearing surface and the preparation of asphalt mastic. Present market conditions appear to indicate that production of bituminous sand in a more or less crude form, and of partially or wholly refined separated bitumen, will somewhat precede production of liquid hydrocarbons.

MARKETS

(*a*) *Crude bituminous sand:*

In the United States, the use of natural rock asphalts has been somewhat restricted owing to severe competition with relatively low-priced domestic petroleum residuum. Nevertheless, during 1925, production of the natural material exceeded 500,000 tons. It appears probable that increasing cost of residuum will be reflected in increased production of rock asphalt.

In the western provinces of Manitoba, Saskatchewan, and Alberta, cost of asphalt residuum varies from $32 to $43 per ton, and consumption for street paving during 1912-13, the last normal year prior to the war, was approximately 17,000 tons. To replace this with a 15 per cent bituminous sand would require approximately 110,000 tons of such material. During recent years, the construction of sidewalks with asphaltic materials has been introduced in western Canada, and an attempt is also being made to extend the use of asphalt mastic. Assuming a period of normal development, it thus appears reasonable to suppose that a very considerable market for bituminous sand may be developed during the next decade. Such development would be materially assisted by the granting of a low-freight classification, such as prevails on similar material in the United States.

(*b*) *Separated and refined bitumen:*

Asphaltic materials are used extensively for a variety of purposes other than paving. Their disassociation and reconstruction constitute an important feature of industrial

research. The finer grades of asphalt are used extensively in the manufacture of paints and varnishes and for electric insulation. Both natural and artificial asphalts are used in making roofing preparations, the former being preferable. Asphalt is also employed in the manufacture of rubber waterproof-cloth and a wide range of rubber goods, in enamelling iron, and as a fuel binder.

It is considered that bitumen separated from bituminous sand is entirely satisfactory when used as a binder in the construction of various types of wearing surfaces; as a basis for the manufacture of bituminous paints, cements, varnishes, enamels, and japans; as a binder for briquetting fuel; and in the production of roofing preparations. Whether present market conditions in western Canada would justify installation of equipment for the manufacture of such products is problematical.

(*c*) *Liquid hydrocarbons:*

Technically and economically, the production of liquid hydrocarbons from Alberta bituminous sand constitutes a many-sided problem, and in certain respects is analogous to that presented by the proposed development of certain petroliferous shales. It is true that the average content of crude petroleum per ton is less than that from many of the shales of New Brunswick, Nova Scotia, and the United States, while it appears that the amount of nitrogen that might be recovered in the form of ammonium sulphate is negligible. On the other hand, cost of mining bituminous sand would certainly, and subsequent cost of recovering the hydrocarbons would possibly, be much lower than in the case of oil shales.

Proposed production of petroleum from Alberta bituminous sand will constitute a problem analagous to the mining and treatment of low-grade ores. Satisfactory financial returns will depend on large through-put capacity, together with able technical, business, and administrative control. Production will be directly affected by the future trend of the petroleum situation in the United States, and the possible development of producing fields in western Canada. The uncertainty of

such production is reflected in a paper presented by Mr. Van H. Manning, late Director, U. S. Bureau of Mines, before the American Society of Mining and Metallurgical Engineers, in 1920; by a paper presented before the same Society in 1922, by Dr. David White, of the U. S. Geological Survey; and in the conclusions arrived at by the Committee of Eleven in 1925.

The importance of production of liquid hydrocarbons from bituminous sand, if commercially feasible, requires no emphasis. Petroleum has become a fundamental necessity in the industrial life of a nation. Those who look beyond periods of temporary overproduction realize that, even with conservation of existing supplies and increased production from present producing sands, the problem of furnishing sufficient oil to meet the inevitable and rapidly increasing demands, is indeed of prime importance.

The value of petroleum products — other than solid and semi-solid asphalts — entered for consumption in the provinces of Manitoba, Saskatchewan, Alberta, and British Columbia, in 1921-22, was $13,111,167, and in 1922-23, $11,998,000.

Administration of bituminous sand leases is within the jurisdiction of the Mining Lands Branch, Department of the Interior. It is considered that regulations governing such leases are such as to discourage speculation and encourage legitimate development.

THE MACKENZIE RIVER AREA*

By G. S. Hume (*Member, C. Inst. M. & M.*)**

Introduction

Within the Mackenzie River basin there are two areas — Great Slave lake and Fort Norman — in which drilling for oil has been carried on. In the Fort Norman area, this drilling has met with some measure of success, but in the Great Slave Lake area results have been negative. There are, however, other large areas presumably underlain by oil-bearing rocks, but a great part of the country away from the main routes of travel is difficult of access and no detailed investigations have yet been undertaken.

Great Slave Lake Area

Location and Physiography

Great Slave lake is the fourth largest lake on the North American continent, being exceeded in size only by lakes Superior, Huron, and Michigan. At no place, however, is it more than 70 miles wide, and it is roughly divisible into three major parts, the north, east, and west arms. The longer axis passes through the east and west arms in a northeast and southwest direction. The main part of the lake is between latitudes 61° and 62°, although a large part of the north and east arms is between latitudes 62° and 63°. The lake stretches from longitude 109° to longitude 117°.

The east arm of the lake lies wholly within an area of pre-Cambrian rocks and, as a consequence, is in contrast with the west arm, which is underlain by Palæozoic and later deposits. The boundary between the pre-Cambrian and Palæozoic follows a northwest direction along the west side of the north arm, but there are isolated patches of Palæozoic rocks within the area of pre-Cambrian along the eastern shore.

*Published with the permission of the Director, Geological Survey of Canada, Ottawa.

**Geological Survey of Canada.

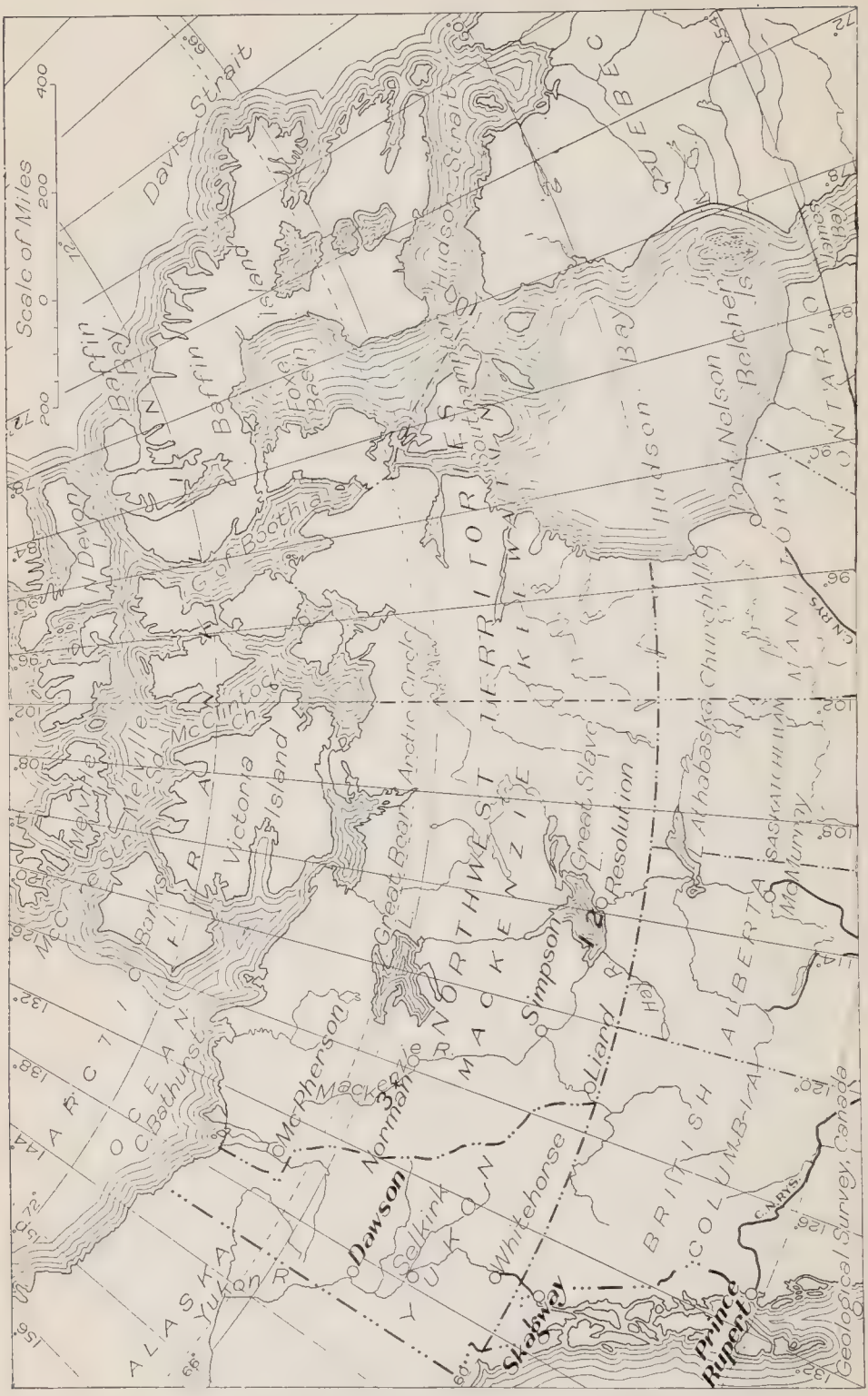


Figure 13.—Northwest Territories.
1—Windy Point; 2—Pine Point; 3—Fort Norman oil area.

The shoreline of the west arm is characterized by wide, shallow bays, separated by low gravelly or rocky points. The country close to the shore is mostly flat and covered with spruce muskeg and poplar ridges. South of the lake, at some considerable distance, there is a sharp rise of 200 to 300 feet to the Alberta plateau (1). Streams and rivers flowing northward pass over the escarpment in falls or cascades. Along the north side of the west arm and a short distance inland there are some low wave-cut cliffs of Palæozoic rocks. Back from the shore numerous long, narrow hills rise 100 to 150 feet (2) above lake-level.

The most pronounced topographic feature of the area is Horn mountain, lying about 50 miles northwest of the west end of Great Slave lake. According to Whittaker (3), it rises 2,000 feet above the level of the flat muskeg plain separating it from Great Slave lake and the Mackenzie river.

Stratigraphy and Structure

With the exception of Horn mountain, which is capped with Cretaceous rocks, the area north of the Alberta plateau in the vicinity of the west arm of Great Slave lake is entirely underlain by Palæozoic rocks. An eastward-facing cuesta of Ordovician and Silurian rocks forms or parallels the western shore of the north arm. No Lower Devonian is present, but, owing to a regional southwest dip, successive horizons of Middle and Upper Devonian rocks outcrop to the west. This succession is modified by a broad anticline extending northwesterly from Pine point, on the south shore of the lake, to Windy point, on the north shore. On Pine point, the lowest of the Middle Devonian formations — the Pine Point limestones — is flanked on either side by the Middle Devonian Presqu'ile dolomites, whereas on the north shore, at Windy point, the Presqu'ile dolomites occur on the axis of the anticline and are flanked on either side by Slave Point limestones, also

(1) Camsell, C., and Malcolm, Wyatt, "The Mackenzie River Basin"; Geol. Surv. of Canada, Mem. 108 (revised edition), p. 17.

(2) Cameron, A. E., "Hay and Buffalo rivers, Great Slave Lake and adjacent Country"; Geol. Surv. of Canada, Sum. Rept., 1921, pt. B.

(3) Whittaker, E. J., "Mackenzie River District between Great Slave Lake and Simpson"; Geol. Surv. of Canada, Sum. Rept., 1921, pt. B. p. 47.

of Middle Devonian age. This arrangement of the strata indicates that the anticline plunges to the northwest. Overlying the Slave Point limestones west of the anticline at Windy point, and covering a large area at the western end of Great Slave lake, are the Upper Devonian Simpson shales. These are fine, fissile, black shales with a maximum thickness of 150 to 250 feet, and they form an effective cover to any lower porous formation.

Oil Prospects

Oil seepages occur at Pine point in the Pine Point limestones, and at Windy point in the Presqu'ile dolomites. These seepages are therefore on the crest of the broad anticline just described. At neither place, however, is there any cover to act as a cap rock, and consequently any oil that may have accumulated near or on the anticline has probably been dissipated through seepage. The best prospective oil horizon appears to be the Presqu'ile dolomites, since these rocks are coarsely crystalline and have a relatively high porosity. The pore spaces of the dolomite are quite apparent in many specimens of the rock, and vugs several inches in diameter and lined with dolomite crystals are filled with semi-liquid bituminous matter. A well was drilled by the Northwest Company at Windy point, close to one of the large seepages, but no oil production was secured. The well started in the Presqu'ile formation and, since effective cover is lacking, there could be no pressure within the Presqu'ile formation to cause oil to flow into the drill hole. The well was continued down into the Pine Point formation, which contains the seepages at Pine point. No oil shows in the Pine Point formation were reported by the Northwest Company, and it appears that at this location, at least, effective porosity is lacking in this formation.

The only other well drilled within the Great Slave Lake area was that of the White Beaver Oil Company, at a location near Hay river and about 15 miles south of Great Slave lake. At this location, the Presqu'ile formation is overlain by the Simpson shale and later Devonian rocks and a structure trending at right angles to the large anticline crossing Great Slave lake is present according to J. J. O'Neill (1). The closure

(1) O'Neill, J. J.: Private communication.

from crest to trough on this structure is about 300 feet, but there may be a southwest plunge to the anticline, since it is thought the regional dip is in that direction. The location of the White Beaver Oil Company's well is considered by O'Neill to be some distance down the plunge of the anticline. The well struck a very large artesian flow of salt water in the Presqu'ile formation, but obtained no oil. It is considered possible that higher points on this anticline might yield oil, since a plausible explanation of the artesian water flow is that it was due to the pressure of gas in higher parts of the structure. But lacking any definite knowledge of closure of the anticline in a northeast direction, it is possible that the artesian water flow is due to some other cause. The country away from the river is heavily wooded, covered with muskeg, and rock outcrops are lacking, so that the closure, if any is present, on the anticline could be proved only by drilling shallow wells to a known horizon.

There is a large area west of the west end of Great Slave lake that is presumably underlain by Simpson shales and higher Devonian rocks. This appears to be the best part of the Great Slave Lake area to prospect for structures, since the cover in this area would be adequate to retain any oil. The seepages of oil at Windy point show that the structure there has been sufficient to concentrate the oil within the Presqu'ile formation, and the failure of the Northwest Company's well is ascribed to lack of cover. The location of anticlines, therefore, within the area to the west of Great Slave lake, would seem to offer good prospects for production at very moderate depths. Very little exploratory work has been done in this area and it is possible the location of anticlines may be very difficult on account of the country being largely covered by spruce muskeg and the probable absence of outcrops.

THE FORT NORMAN AREA

Location and Physiography

The Fort Norman area lies north of latitude 65° and in the vicinity of longitude 127°. Fort Norman is at the junction of Great Bear and Mackenzie rivers, and the area tested by drilling is approximately 50 miles northwest.

The Mackenzie lowland through which Mackenzie river flows has a general northward slope. In the vicinity of the Fort Norman oil area, the lowland is a relatively narrow strip of country not more than 20 miles wide between the Norman Mountain range on the east and the Carcajou mountains on the west. The Norman range rises approximately 2,500 feet above Mackenzie river; whereas Carcajou mountains are higher and more rugged. The country between the mountain is relatively flat and is heavily forested with small spruce, poplar, and alder. It is covered by muskeg, in which there are innumerable lakes and sloughs, many of which lack any well defined drainage outlet. A few feet below the muskeg surface, even in summer, a layer of ice is present in many places, and presumably the ground at a slight depth below the surface is permanently frozen, thus accounting for the poorly developed drainage system.

Stratigraphy

The rocks of the Fort Norman area range from Cambrian to Eocene, but the Devonian is the only known oil-bearing formation. No Lower Devonian is present, but heavy-bedded limestones of Middle Devonian age are overlain by 1,000 to 1,500 feet of black shales of the Fort Creek formation, and these in turn are overlain by more than 1,600 feet of alternating shales and sandstones of the Bosworth formation. Both the Fort Creek and Bosworth formations are Upper Devonian. The Upper Devonian, in some places, is overlain by a thick series of Cretaceous strata, consisting of non-marine and coal-bearing sandstones and shales overlain by marine black shales. In other places, non-marine Eocene beds rest directly on the Upper Devonian Bosworth formation. The marine shales of the Cretaceous would, presumably, form an effective cover for any oil that might accumulate in either the basal sandstones of the Cretaceous or in the Bosworth formation, but where the two productive wells were drilled, although the Bosworth formation outcrops in their vicinity, the oil came from the shales of the Fort Creek formation.

Structure and Oil Prospects

Between the Norman mountains east of Mackenzie river and the Carcajou mountains on the west there is a basin structure, about 20 miles wide in the vicinity of the oil wells. The Norman range is anticlinal, but there is more complicated folding and faulting in the Carcajou mountains. The lowest rocks that appear at the crest of the Norman range are Silurian. To the west, successively higher strata appear and the Upper Devonian Bosworth formation has its greatest development along the east side of the Mackenzie river. Cretaceous, strata cover most of the area west of the Mackenzie, to where the upturned edges of lower formations appear on the flanks of the Carcajou mountains. The numerous soft sandstone beds in the Bosworth formation seem to have offered favourable conditions for oil accumulation, and many seepages of oil occur at the outcrop of rocks of this age on the east side of the Mackenzie. The occurrence of oil seepages, and springs of water as well, suggests an underground water movement, and, as the outcrops of the Bosworth formation along the eastern edge of the Carcajou mountains are higher than those along the western flank of the Norman range, movement of water in the basin is presumably from west to east. Under such conditions water would enter the Bosworth formation at the outcrops on the edge of the Carcajou mountains and pass eastward through the basin to issue as springs on the eastern edge. Such a movement of water would tend to move the oil in the Bosworth formation towards the eastern side of the basin, and hence the presence of the numerous seepages would be explained, although such seepages might result from the movement of oil up the dip on account of buoyancy of the oil. If this were the case, however, seepages should occur along the outcrop of the Bosworth formation on the flank of the Carcajou mountains. Data on the outcrops of the Bosworth formation near the Carcajou mountains are very limited on account of the inaccessibility of the area, but the sections that were studied by the writer showed no trace of oil seepages. Their absence would be satisfactorily explained by a water

movement in the basin-structure from west to east and, in view of the seepages of oil and springs of water on the east side of the basin, it appears a fair conclusion that such is the case.

Two productive wells were drilled by the Northwest Company and yielded 36° Beaume oil at an estimated rate of 100 barrels per day. The two wells are close together on the east bank of the Mackenzie river, that is, on the east side of the basin structure. The Bear Island well of the same company was drilled west and slightly south of the two discovery wells.

Figure 14.—Discovery well, Fort Norman.

This well found a show of oil at the contact between the Middle and Upper Devonian, but at a still lower depth, in the Middle Devonian, salt water was encountered. Another well, known as 'C' location, was drilled by the Northwest Company on the west side of Mackenzie river, almost due south of the Discovery wells. This well finished as a dry hole in the Middle Devonian limestones. Thus no production was secured down the dip from the Discovery wells, which were drilled close to a seepage. It is not evident, however, from data available, why there should be a concentration of oil in the Fort Creek shales at the Discovery wells, since no local folding on the basin-structure is apparent at this locality and the oil apparently comes from

the shales themselves rather than from sand members in the shales. It is possible, however, that the migration of oil up the dip east of the Discovery wells was prevented by a sealing of the outlet at the outcrop of the oil horizon by the formation of a tarry residue, or possibly there is a local area of concentration of oil in the shales and the impervious character of the shales themselves prevented escape of the oil. In either case, since the oil horizon occurs in shales without sands being present, the area of concentration of oil would probably be very limited, and on the basis of the oil discovery in the Fort Creek shales there is no reason to assume a large productive field.

It does not appear to the writer, however, that prospects within this area are confined to the locality where production has been secured. If there is a water movement in the basin from west to east, it would be likely that subsidiary folds on the basin-structure should act as traps for the concentration of oil, and this would be particularly the case if such folds occurred toward the east side of the basin where seepages are abundant. The Bosworth formation, on account of the presence of numerous sand horizons and seepages at the outcrop on the east side of the Mackenzie, would seem to be the most favourable prospective formation. West of the Mackenzie river, the Bosworth formation is overlain by non-marine sands and shales of Cretaceous age, and these in turn by dark marine Cretaceous shales. Subsidiary folds in this part of the basin, where the Cretaceous shales form an effective cover, may have resulted in the accumulation of oil in the Bosworth or lower formations, and also possibly in the basal Cretaceous sands. Several cross folds are known within the basin-structure, but in all cases Devonian rocks occur at the crests of these anticlines. However, the existence of these folds suggests the possible presence of others where the Cretaceous is still present, and the prospects for large production within this basin appear, therefore, to depend on their location. No detailed work with the object of locating such folds has been undertaken by the Geological Survey, and since the country is for the most part heavily wooded or muskeg-covered, their discovery may be a very difficult matter.

NATURAL GAS IN CANADA*

By R. T. Elworthy (*Member, C. Inst. M. & M.*)**

Introduction

Canada has a relatively small share of the great resources of natural gas and petroleum on the North American continent. Unfortunately for the present generation, like her resources of coal, the greater part of this gas and oil is in the west, and, therefore, the industrial and more populated provinces of Ontario and Quebec cannot utilize those supplies which, if available, would go far to afford a solution of one of central Canada's most pressing problems—a supply of cheap fuel.

Natural gas, together with oil, is obtained in southwestern Ontario, but in decreasing quantity since 1890, and there has never been sufficient available to supply Toronto, nor for large industrial use in the many manufacturing towns such as Kitchener, Galt, Brantford, etc., lying between Toronto, Windsor, and Sarnia. By government supervision and the application of methods of conservation, a supply of natural gas for domestic lighting and heating has been maintained in the southwestern part of Ontario, but the fields are on the wane.

In Alberta, on the contrary, owing to the great activity in drilling for oil during the past five years, particularly in the Turner Valley field, southwest of Calgary, and in the Wainwright field, east of Edmonton, large flows of natural gas have been opened up, presenting the problem of how their vast supply can be utilized to the greatest advantage.

Apart from these two provinces, there are no other known commercial reserves of natural gas in Canada, save in New Brunswick, where one small field yields gas supplying the town of Moncton; and it is only in Alberta that there is any present prospect of increasing supplies.

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**Mines Branch, Department of Mines, Ottawa.

THE CHIEF GAS FIELDS IN CANADA

The only field in New Brunswick is the Stony Creek field, a small area covering about twenty square miles, nine miles from the town of Moncton, and situated on the west bank of the Petit-Codiac river. Drilling for oil was carried on at intervals from 1860 to 1906. In the latter year, the New Brunswick Oil and Gas Company commenced to develop the field more systematically, and today there are about seventy wells drilled, thirty of which are productive of oil and gas. Most of the wells reach depths ranging from two thousand to twenty-five hundred feet, and six different gas and oil sands have been recognized. These are sandstone beds in the Albert series.

The composition of the gas from the different sands varies little, having as its chief constituents 75 to 80 per cent of methane, 20 per cent ethane, and 2 to 7 per cent nitrogen. The helium content is low, with an average of about 0.05 per cent.

In Ontario natural gas is found in commercial quantities in the southwestern corner of the Province, mainly in the counties of Lambton, Kent, Norfolk, Haldimand, and Welland, bordering the shore of lake Erie.

All these fields are declining and little new drilling is in progress.

Detailed information on the Ontario fields is available in the annual reports on natural gas and petroleum, published by the Ontario Department of Mines, and their history and development is summarized elsewhere in this series of papers.

The Province of Alberta has the largest production of natural gas, as well as the greatest potential supply, in Canada, and as previously stated, the problem has already arisen of the economic utilization of the large flows frequently opened-up in the search for oil, particularly in the Turner valley.

The main gas fields lie in the south and central portion of the Province, mainly to the east of a line joining Calgary and Edmonton, the Turner Valley field being the one exception. The four most developed fields are situated near the main

railway lines, the Medicine Hat and Bow Island fields on the Canadian Pacific, and the Wainwright and Viking fields on the Canadian National main lines, respectively.

Natural gas is also found in the northern part of the Province, but owing to the unsettled nature of the country and the lack of transportation facilities, exploratory drilling has only been carried out along, or near, the banks of the Peace and Athabaska rivers.

The Turner Valley field, lying in the foothills of the Rockies, about forty miles southwest of Calgary, has become the most important in Canada since the Imperial Oil Company, in drilling Royalite No. 4 well, opened up a very large gas flow, amounting to over twenty million cubic feet per day, from which more than 500 barrels of crude naphtha per day is separated. During the last two years there has been great activity in this field, and three more wells have been successfully drilled to the productive formations and are yielding a similar light oil.

The gas from these wells carries a large amount of impurities in the form of sulphur compounds, about 650 grains per 100 cubic feet, or almost 1 per cent by volume. A Koppers liquid purification system has been installed, in which the gas, at 300 pounds per square inch pressure, is scrubbed by a solution of sodium carbonate, which is afterwards reactivated by blowing air through it.

The problem of the economic utilization of the 20-30 million cubic feet of gas a day from the few wells now producing in this field, with the probability that this volume may be doubled or trebled within the next year, is a serious one. The domestic and industrial demand for the gas as fuel cannot possibly reach this amount for many years. Unless some use is found, the gas will be allowed to go to waste.

CHEMICAL COMPOSITION OF THE GAS

With the exception of the Turner Valley gas, all natural gas in Canada is what is termed 'dry gas', that is, it contains insufficient gasoline hydrocarbons to warrant consideration of recovering gasoline. The gases from the Stony Creek

field, New Brunswick, are composed of 75 to 80 per cent methane and 18 to 20 per cent ethane, together with 2 to 7 per cent nitrogen, depending on whether they issue from oil wells or from dry sands.

In Ontario, the average composition of natural gas is about 80 per cent methane, 12 per cent ethane and 8 per cent nitrogen. As is usual in fields in which the supply is declining, the ethane and higher hydrocarbon content has increased slightly since the Ontario Department of Mines carried out a survey (1) in 1912-1914. Many analyses have been made during the last three years as part of the investigation of the helium resources of Canada.

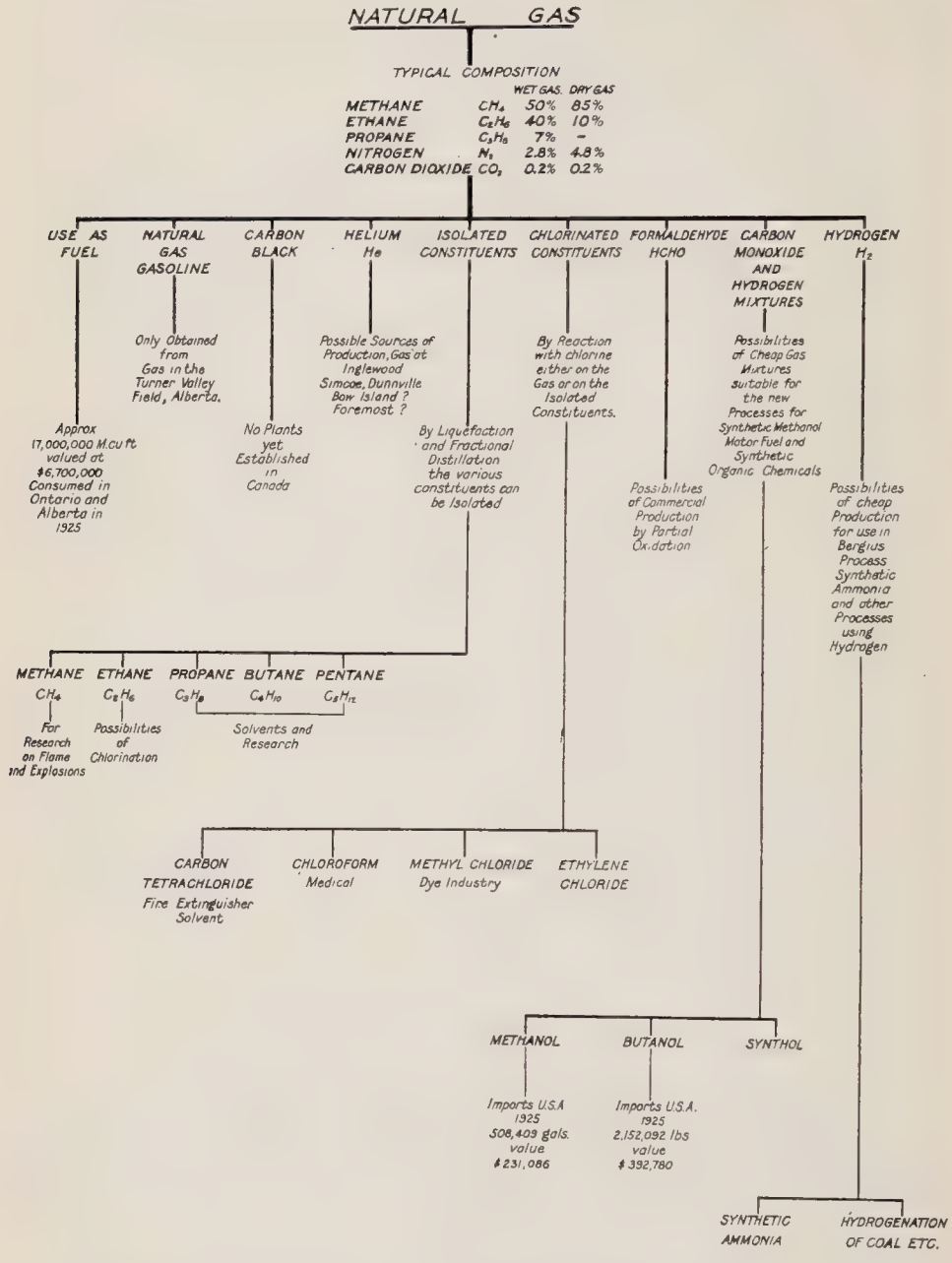
Natural gas in Alberta is characterized by its high methane content. Gases from the Athabaska, Viking, Wainwright, Medicine Hat, Bow Island, Foremost, and Coutts-Sweetgrass fields all consist of 90 per cent, and often 95 per cent, methane. The remaining ten to five per cent is ethane and nitrogen. The Turner Valley field yields gas with a greater higher-hydrocarbon content, ordinary combustion analysis—which shows its limitations when used on gases of this character—giving 30 to 50 per cent ethane and 50 to 70 per cent methane.

Detailed analyses of gases from all the gas fields in Canada are given in a recent report of 'Helium in Canada', issued by the Mines Branch, Dominion Department of Mines (Memoir No. 679, 1926).

PRODUCTS FROM NATURAL GAS

Natural gas, originally used only as fuel, is more and more becoming a source of valuable industrial chemical products, such as natural-gas gasoline, carbon black, helium, pure hydrocarbons, such as methane, ethane, butane, ethylene, and the halogen derivatives of these compounds, such as methyl and ethyl chlorides, chloroform, and ethylene dichloride. (See accompanying Figure). There are great possibilities for the production of cheap hydrogen from

(1) Ontario Department of Mines, Annual Report, 1914, Vol. 23, pp. 237-273.


NATURAL GAS
TYPICAL COMPOSITION
WET GAS. DRY GAS
METHANE CH4 50% 85%
ETHANE C2H6 40% 10%
PROPANE C3H8 7% -
NITROGEN N2 2.8% 4.8%
CARBON DIOXIDE CO2 0.2% 0.2%
USE AS FUEL
NATURAL GAS GASOLINE
CARBON BLACK
HELIUM He
ISOLATED CONSTITUENTS
CHLORINATED CONSTITUENTS
FORMALDEHYDE HCHO
CARBON MONOXIDE AND HYDROGEN MIXTURES
HYDROGEN H2
Approx 17,000,000 M.cu ft valued at $6,700,000 Consumed in Ontario and Alberta in 1925
Only Obtained from Gas in the Turner Valley Field, Alberta.
No Plants yet Established in Canada
Possible Sources of Production, Gas at Inglewood Bow Island ? Foremost ?
By Liquefaction and Fractional Distillation the various constituents can be Isolated
By Reaction with chlorine either on the Gas or on the Isolated Constituents.
Possibilities of Commercial Production by Partial Oxidation
Possibilities of Cheap Gas Mixtures suitable for the new Processes for Synthetic Methanol Motor Fuel and Synthetic Organic Chemicals
Possibilities of cheap Production for use in Bergius Process Synthetic Ammonia and other Processes using Hydrogen
METHANE CH4
ETHANE C2H6
PROPANE C3H8
BUTANE C4H10
PENTANE C5H12
For Research on Flame and Explosions
Possibilities of Chlorination
Solvents and Research
CARBON TETRACHLORIDE Fire Extinguisher Solvent
CHLOROFORM Medical
METHYL CHLORIDE Dye Industry
ETHYLENE CHLORIDE
METHANOL
BUTANOL
SYNTHOL
Imports U.S.A 1925 508,409 gals. value $231,086
Imports U.S.A. 1925 2,152,092 lbs value $392,780
SYNTHETIC AMMONIA
HYDROGENATION OF COAL ETC.

PRODUCTS, PRESENT AND POSSIBLE, FROM NATURAL GAS

R.T.E.

Figure 15.

methane. Unfortunately, little has yet been done on the production of any of these substances in Canada. The domestic demand for most of such products is small, while tariffs and high freight rates militate against a profitable export business.

Natural-gas gasoline is the only exception, and it can only be, and is, obtained from gases in the Turner Valley field. This production is, however, only a small proportion of the total consumption of gasoline in Canada.

The Turner Valley field yields the only gas in Canada which is suitable for carbon-black manufacture. Up to the present, no plant has been established, although the subject has received some consideration. The process of making carbon black, that of burning natural gas in an insufficient supply of air and collecting the fluffy light carbon so formed, is very inefficient, and its practice, except in remote fields where the prospective domestic and industrial demand is far distant, is not encouraged.

The isolation of the various hydrocarbons composing natural gas, carried out by a process of liquefaction and rectification, analogous to the process of obtaining oxygen and nitrogen from the air, is being carried on commercially in the United States. Several chemicals of coming importance —for example, ethylene dichloride—are being manufactured from the hydrocarbons so obtained. Hydrogen can also be produced from methane by passing it with steam over catalytic iron oxide at a high temperature, and subsequently removing the carbon monoxide and dioxide also formed. This process is in operation in Germany, in the Bergius process for the hydrogenation of coal, where the exit gases from the hydrogenation bombs are treated for the production of hydrogen to be used for the hydrogenation process. In view of the possibilities for the Bergius process in western Canada when economic conditions warrant its establishment, the large supplies of cheap high-methane natural gas may be a valuable asset.

HELIUM

A thorough search for helium has been carried out by the Federal Department of Mines during the last five years, but it has not been found present in commercially extractable quantity in any gas in western Canada, with the possible exception of that of the Bow Island field. Gas in this field contains about 0.3 per cent helium, but unfortunately the field is one of the oldest in Canada and is now becoming exhausted. Gases in the Turner Valley and Coutts-Sweetgrass fields, where the greatest volumes are obtainable, carry helium in negligible quantity.

In Ontario, several small fields are known, the gas from which has a helium content of from 0.3 to 0.4 per cent. These are mainly in Norfolk county, and it is thought that, if an industrial demand for helium arose, it might be economically extracted from the natural gas consumed or metered in Simcoe and Dunnville and neighbourhood in southwestern Ontario. One small field at Inglewood, a village fifteen miles north of Brampton, Ontario, was found where the gas has a helium content of 0.8 per cent, equal to that of the natural gas from which helium is recovered in the United States Government plant at Fort Worth, Texas. The Ontario Government has taken up many of the leases in this area, and it is hoped that an experimental extraction station will be established before long, where the helium from the gas in this area, which at present is not even developed sufficiently for domestic use, will be extracted to provide at least a supply for the maintenance of the valuable low-temperature research work being carried on at the University of Toronto under Prof. J. C. McLennan, and to provide a source of helium for industrial and scientific research in Great Britain. Canada possesses the only known source of helium in the British Empire, and although there has not been sufficient found to provide for liberally supplying any future airship service, the possible smaller industrial uses of helium, such as for deep diving and caisson work, would seem to justify at least experimental production from our known supplies.

PETROLEUM AND ITS PRODUCTS IN CANADA

A Statistical Study

By S. J. Cook (*Member, C. Inst. M. & M.*)*

Crude Petroleum

Prior to 1925, and as far back as 1881, the earliest year for which records are available, Canada's production of crude petroleum was obtained, almost entirely, from wells situated in the Province of Ontario. Beginning in 1910, and continuing to date, New Brunswick oil wells have yielded a few thousand barrels annually. Alberta's contribution to the petroleum output of Canada really began in 1917, although small quantities had been produced in earlier years; production rose in the next two years, but thereafter declined until, in 1924, there was only a very small quantity of oil taken from the wells. Then, with the bringing-in of the now famous Royalite No. 4 well, the output of the Province advanced sharply in 1925, and production in 1926 reached an even greater volume.

Available records show a grand total of 22,600,000 barrels (791,000,000 Imp. gallons) of oil taken from Canadian wells from 1881 to 1926. Complete records of values are not obtainable, owing to the lack of data for the earlier years, when only quantities were noted; but a close estimate of the value represented by Canada's output of crude petroleum would be about $35,000,000.

The rise in production from Ontario wells carried the annual output above 500,000 barrels in 1884, and for the next twenty-five years production continued on this scale, the record output being attained in 1894 when the total for the year reached 829,104 barrels. In 1908 and 1909, the beginning of a recession in production became apparent, and since 1908 there has not been a single year when production even approached half-a-million barrels. In 1926, the total for the Province was 137,850 barrels.

Table 1 shows the quantity and value of the production of crude petroleum from Canadian wells by years since 1881, for each of the several oil-producing provinces.

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TABLE 1—PRODUCTION OF CRUDE PETROLEUM IN CANADA BY PROVINCES, 1881-1926

(Barrel=35 Imp. gal.)

	New Brunswick		Ontario		Alberta		Canada	
	Barrels	Value ($)	Barrels	Value ($)	Barrels	Value ($)	Barrels	Value ($)
1881	.....	.....	368,987	.....	.....	.....	368,987	.....
1882	.....	.....	389,573	.....	.....	.....	389,573	.....
1883	.....	.....	472,866	.....	.....	.....	472,866	.....
1884	.....	.....	571,000	.....	.....	.....	571,000	.....
1885	.....	.....	587,563	.....	.....	.....	587,563	.....
1886	.....	.....	584,061	525,655	.....	.....	584,061	525,655
1887	.....	.....	713,728	556,708	.....	.....	713,728	556,708
1888	.....	.....	695,203	713,695	.....	.....	695,203	713,695
1889	.....	.....	704,690	653,600	.....	.....	704,690	653,600
1890	.....	.....	795,030	902,734	.....	.....	795,030	902,734
1891	.....	.....	755,298	1,010,211	.....	.....	755,298	1,010,211
1892	.....	.....	779,753	984,438	.....	.....	779,753	984,438
1893	.....	.....	798,406	874,255	.....	.....	798,406	874,255
1894	.....	.....	829,104	835,322	.....	.....	829,104	835,322
1895	.....	.....	726,138	1,086,738	.....	.....	726,138	1,086,738
1896	.....	.....	726,822	1,155,647	.....	.....	726,822	1,155,647
1897	.....	.....	709,857	1,011,546	.....	.....	709,857	1,011,546
1898	.....	.....	758,391	1,061,747	.....	.....	758,391	1,061,747
1899	.....	.....	808,570	1,202,020	.....	.....	808,570	1,202,020
1900	.....	.....	710,498	1,151,007	.....	.....	710,498	1,151,007
1901	.....	.....	622,392	1,008,275	.....	.....	622,392	1,008,275

	New Brunswick		Ontario		Alberta		Canada	
	Barrels	Value ($)	Barrels	Value ($)	Barrels	Value ($)	Barrels	Value ($)
1902	.....	.....	530,624	951,190	.....	.....	530,624	951,190
1903	.....	.....	486,637	1,048,874	.....	.....	486,637	1,048,874
1904	.....	.....	503,474	935,895	.....	.....	503,474	935,895
1905	.....	.....	634,095	856,028	.....	.....	634,095	856,028
1906	.....	.....	569,753	761,760	.....	.....	569,753	761,760
1907	.....	.....	788,872	1,057,088	.....	.....	788,872	1,057,088
1908	.....	.....	527,987	747,102	.....	.....	527,987	747,102
1909	.....	.....	420,755	559,604	.....	.....	420,755	559,604
1910	1,485	1,826	314,410	386,724	.....	.....	315,895	388,550
1911	2,461	3,019	288,631	354,054	.....	.....	291,092	357,073
1912	2,679	3,799	240,657	341,251	.....	.....	243,336	345,050
1913	2,111	3,762	225,969	402,677	.....	.....	228,080	406,439
1914	1,725	2,742	212,693	338,182	387	2,200	214,805	343,124
1915	1,020	1,423	214,444	299,149	.....	‡	215,464	300,572
1916	1,345	2,663	196,778	389,621	.....	‡	198,123	392,284
1917	2,341	5,460	202,991	473,477	8,500	63,302	213,832	542,239
1918	3,009	7,402	288,692	777,737	13,040	100,004	304,741	885,143
1919	4,225	13,141	219,804	625,342	16,437	97,841	240,466	736,324
1920	5,148	19,963	180,071	726,286	11,032	75,986	196,251	822,235
1921	7,479	33,022	172,859	559,198	7,203	49,313	187,541	641,533
1922	7,778	32,732	164,731	526,316	6,559	52,128	179,068	611,176
1923	8,826	35,642	159,400	478,149	1,943	8,227	170,169	522,018
1924	5,561	21,313	154,368	441,952	844	4,135	160,773	467,400
1925	5,376	18,756	143,134	386,555	183,491	845,394	332,001	1,250,705
1926	10,544	29,940	137,850	379,221	216,050	902,504	364,444	1,311,665
Total	73,113	236,605	22,087,609	†29,537,030	465,486	2,201,034	22,626,208	†31,974,669

(†) Total value from 1886 to 1926.

(‡) Small production—no record.

Canada's production of crude petroleum in 1925 and 1926 was drawn chiefly from the wells of Alberta and Ontario, with relatively small amounts from the wells of New Brunswick. In each of these two years, Alberta was the principal producer, displacing Ontario. As noted above, this situation was partly due to the decreased production in Ontario and partly to the bringing-in of highly productive wells in Alberta.

Petroleum wells in operation in Canada numbered 2,885 in 1925, distributed as follows: 2,862 in Ontario; 14 in New Brunswick; and 9 in Alberta.

Table 2 shows the principal statistics of the crude-oil industry in Canada for the years 1921-1925.

TABLE 2—PRINCIPAL STATISTICS OF THE PETROLEUM INDUSTRY IN CANADA 1921-1925

Year	Number of firms	Number of wells	Capital employed	Number of employees	Salaries and wages	Selling value of products
			$		$	$
1921.....	120	3,009	3,214,159	190	215,791	641,533
1922.....	120	2,880	2,764,099	160	167,176	611,176
1923.....	117	2,694	2,934,213	151	118,231	522,018
1924.....	119	2,473	5,650,086	158	152,957	467,400
1925.....	180	2,885	7,954,722	259	318,101	1,250,705

Bounties

With a view to encouraging the production of oil from Canadian wells, the Dominion Government passed an Act in 1904 providing for "the payment of a bounty of 1½ cents per Imperial gallon on all crude petroleum produced from wells in Canada on and after the eighth day of June, 1904—said bounty to be paid to the producer of the petroleum."

In 1907, the Act was amended by the addition of the words "or to such other persons interested, as the Governor-in-Council by regulation approves."

In 1908, the payment of bounties was limited by defining the oil on which payment of bounty might be made as that "having a specific gravity of not less than 0.8325 at 60°

Fahrenheit produced from wells in Canada or from shales or other substances mined in Canada on or after the date on which this Act goes into force—the said bounty to be paid to the producer of the petroleum or to such other person interested as the Governor-in-Council by regulation approves."

In 1909, a further modification in the wording of the Act in respect to persons to whom bounty should be paid was made as follows: "The said bounty to be paid to or divided amongst the producers of the petroleum, the owner or occupier of the soil through which it is mined or won or such other person interested or injuriously affected by the mining operations or works as the Governor-in-Council by regulation approves".

A further limitation, this time in the amount of bounty payment, was made on June 30th, 1923, in which the following periods and rates of payments were established:

"The said bounty shall be paid during the periods and at the rates following, that is to say:

> "On such crude petroleum produced on or before the thirtieth day of June, one thousand nine hundred and twenty-four, a bounty of one and one-half cents per Imperial gallon shall be paid;
>
> "On such crude petroleum produced on or after the first day of July, one thousand nine hundred and twenty-four, and not later than the thirtieth day of June, one thousand nine hundred and twenty-five, a bounty of three-quarters of one cent per Imperial gallon shall be paid;
>
> "On such crude petroleum produced on and after the first day of July, one thousand nine hundred and twenty-five, no bounty shall be paid."

As a result of the foregoing regulations, the payment of bounty was discontinued on July 1st, 1925.

Table 3 shows the production of crude petroleum in Canada, and the bounty paid, in each year 1905-1925. In this connection it may be noted that practically all the bounty paid during the years 1905-1925 was on oil produced

from Ontario wells. The Alberta oil, in most cases, was too light to win bounty, and the production of oil in New Brunswick was relatively small.

TABLE 3—PRODUCTION OF CRUDE PETROLEUM IN CANADA AND BOUNTY PAID, 1905-1925

Calendar Year	Barrels	Bounty paid	Calendar Year	Barrels	Bounty paid
1905.....	634,095	$332,900	1916.....	198,123	$ 104,014
1906.....	569,753	299,120	1917.....	213,832	107,799
1907.....	788,872	414,158	1918.....	304,741	153,958
1908.....	527,987	277,193	1919.....	240,466	119,714
1909.....	420,755	220,897	1920.....	196,251	97,700
1910.....	315,895	165,845	1921.....	187,541	94,677
1911.....	291,092	152,823	1922.....	179,068	91,103
1912.....	243,336	127,751	1923.....	170,169	86,990
1913.....	228,080	119,742	1924.....	160,773	63,857
1914.....	214,805	112,569	1925*.....	332,001	22,103
1915.....	215,464	112,577			
			Total.....	6,633,099	3,277,490

*Bounty paid to July 1st, 1925.

Imports

Very large quantities of crude petroleum are imported into Canada every year for various purposes, but chiefly to provide the necessary raw materials for the several petroleum refineries throughout the Dominion. It is probable that three-quarters of the total cost of crude petroleum imported into Canada is spent for crude oil that is subsequently refined in Canada.

A glance at the statistics of petroleum importations into Canada since 1880 reveals a wonderful development in this branch of foreign trade. In 1880, the value of petroleum products brought into Canada was $221,143, and of this sum $213,320 was spent for United States oils. Twenty years later, in 1900, the value of oil importations for the first time rose above the one-million dollar mark. Five years later, in 1905, imports were valued at $2,481,072, and still nearly all the oil brought into Canada was obtained from United States sources. In 1910, imports were valued at almost

TABLE 4—IMPORTS OF PETROLEUM, ASPHALT, AND THEIR PRODUCTS INTO CANADA, 1880-1925
(Fiscal years, ending March 31st)

	1880	1885	1890	1895	1900	1905	1910	1915	1920	1925
(a) Total importations										
Asphalt and its products $	523	3,555	68,454	41,817	68,748	133,615	404,524	700,715	466,799	333,290
Petroleum oils, crude, fuel and gas $	.....	.....	.....	4	23,244	901,413	1,189,071	5,235,915	20,306,693	24,396,876
Petroleum oils, refined, gasoline $	.....	.....	.....	.....	.....	.....	817,546	2,828,383	1,288,56€	9,769,545
Other refinery products $	220,620	617,536	767,451	647,740	1,003,138	1,446,044	1,701,585	2,491,067	10,033,23€	3,605,767
Total $	221,143	621,091	835,905	689,561	1,095,130	2,481,072	4,112,726	11,256,080	32,095,288	38,105,478
(b) Imports from United States										
Asphalt and its products $	241	3,422	42,597	3,361	64,330	131,916	332,402	551,729	465,970	331,095
Petroleum oils, crude, fuel and gas $				4	23,244	901,301	1,184,817	5,149,118	17,336,951	20,625,509
Petroleum oils, refined, gasoline $	.....	.....	.....	.....	.....	.....	817,546	2,828,383	1,287,01€	9,769,113
Other refinery products $	213,079	609,791	760,536	630,927	982,062	1,421,266	1,650,925	2,401,586	9,436,004	3,567,783
Total $	213,320	613,213	803,133	634,292	1,069,636	2,454,483	3,985,690	10,930,816	28,525,941	34,293,500
(c) Imports from Mexico										
Asphalt and its products $							60,237	127,772		
Petroleum oils, crude, fuel and gas $									1,560,611	1,169,295
Total $							60,237	127,772	1,560,611	1,169,295
(d) Imports from Peru										
Petroleum oils, crude, fuel and gas $	.....	.....	.....	.....	.....	.....	.....	86,521	1,409,131	2,532,828
Other refinery products $									573,419	.....
Total $	.....	.....	.....	.....	.....	.....	.....	86,521	1,982,550	2,532,828

double the sum paid out in 1905, and in that year for the first time relatively small amounts of oil were obtained from Mexico. In the next sixteen years, from 1910-1926, the imports of oil grew enormously, due largely to the development of the automobile industry. In the fiscal year ending March 31st, 1926, Canada's imports of petroleum products reached a grand total value of $46,059,810, and in the twelve months ending December, 1926, the aggregate stood at $52,508,042. The contrast between this value and $221,143, representing imports in 1880, emphasizes the tremendous development of the petroleum industry in America.

While Canada still buys most of the imported oil from the United States, there has been a change in the foreign trade, due to the development of imports from Mexico and Peru. Whereas, in 1910, the value of oil imported from Mexico was only $60,237, imports in 1920 were valued at $1,560,611, and in 1925 and 1926 the value of petroleum products obtained from Mexico was maintained at about the same sum as in 1920. Canada's imports from Peru, first noted in 1915 when $86,521 represented the value of the imports from this source, have grown appreciably until, in 1920, the value stood at $1,982,550; in 1925, at $2,532,828; and in 1926, at $5,558,895.

Table 4 shows the imports of petroleum into Canada by fiscal years (ending March 31st) for each five-year period from 1880-1925, division of the table being made to show (a) total importations; (b) imports from the United States; (c) imports from Mexico; (d) imports from Peru.

Exports

Canada has not yet been able to produce a sufficient supply of crude petroleum to permit the export of oil to other countries, so the foreign trade in petroleum is largely a matter of import trade into Canada. There are, however, some international dealings between the western United States and Canada's western provinces that are of interest. Crude oil imported from the Montana field has been treated in Alberta's refineries for the recovery of gasoline that finds a ready market for the operation of automobiles and tractors

TABLE 5—EXPORTS OF PETROLEUM AND ITS PRODUCTS FROM CANADA, 1880-1925

(Fiscal years, ending March 31st)

	1880	1885	1890	1895	1900	1905	1910	1915	1920	1925
Oil, petroleum, crude.										
Gal	7,850	954,966	352,050	58,085	.....	4,195	.....	17,120	1,289,259	21,836,577
$	548	27,303	15,294	3,031	.....	211	.....	1,177	84,373	663,072
Oil, coal and kerosene, refined.										
Gal	2,761	.....	6,754	5,458	6,758	2,246	9,093	1,256	2,757,581	1,569,932
$	501	.....	518	541	1,653	480	1,155	235	351,890	164,649
Oil, gasoline and naphtha.										
Gal	.....	.....	.....	.....	.....	.....	.....	37,849	1,311,996	1,438,786
$	.....	.....	.....	.....	.....	.....	.....	10,319	356,376	263,158
Oil, mineral, n.o.p.										
Gal	.....	.....	.....	.....	.....	.....	.....	.....	165,033	717,123
$	.....	.....	.....	.....	.....	.....	.....	.....	53,593	163,584
Wax, mineral.										
Cwt	.....	.....	.....	.....	.....	.....	.....	.....	49,840	30,479
$	.....	.....	.....	.....	.....	.....	.....	.....	384,005	149,045
Total petroleum and its products $	1,049	27,303	15,812	3,572	1,653	691	1,155	11,731	1,230,237	1,403,508

TABLE 6—EXPORTS OF PETROLEUM AND ITS PRODUCTS FROM CANADA, 1920-1926

(Canadian produce)

	1920	1921	1922	1923	1924	1925	1926
Oil, coal and kerosene.....$	293,325	375,820	288,828	138,381	529,497	346,512	851,750
Oil, coal and kerosene, refined...$	205,999	209,282	136,834	139,924	165,520	155,783	192,988
Oil, gasoline and naphtha.....$	59,432	212,638	510,037	263,326	256,966	333,330	773,958
Oil, mineral, n.o.p.....$	.....	31,279	206,709	223,511	161,259	287,463	200,562
Wax, mineral.....$	230,172	7,552	45,526	206,575	147,810	82,999	62,329
Total.....$	788,928	836,571	1,187,934	971,717	1,261,052	1,206,087	2,081,587

on the prairies. There is less market in the Canadian west for the fuel-oil fraction and, as a result, it has been the practice to export quantities of this oil to points in the western States, where it finds a ready sale.

Table 5 shows the exports of Canadian petroleum by fiscal years, for each five-year period, 1880-1925.

Canada's exports of gasoline have grown in the past six years from 160,433 gallons in 1920 to 3,867,536 gallons in 1926. The United States and Newfoundland are Canada's principal customers in this respect, but small shipments are also made to a number of other countries. In a previous paragraph mention was made of the exports of fuel and gas oils. In Table 5 there is an item of 'Oil, coal and kerosene, crude', representing a considerable volume of trade, amounting to more than 21 million gallons in 1926; it is understood that this item represents the exports of fuel oil previously noted. There has been a fairly consistent export of coal oil or kerosene during the past seven years; most of the export trade in this commodity being to the neighbouring country of Newfoundland.

Table 6 shows the export of petroleum and its products from Canada, 1920-1926.

Refining

Canadian refineries, situated at strategic points across the Dominion for convenience in marketing their products, treat annually about 6 million gallons of crude oil from Canadian wells, and about 400 million gallons of imported oils obtained chiefly from the United States, Mexico, and Peru.

There are now 13 plants in Canada engaged in the refining of oils for the production of gasoline, kerosene, lubricating oils, waxes, and petroleum coke. Of these, 3 are located in Ontario, 3 in Alberta, 2 in British Columbia, 2 in Quebec, and one in each of the provinces of Nova Scotia, Manitoba, and Saskatchewan. Eight other plants make lubricating oils and greases as their principal product. Of these, 5 are located in Ontario, and one in each of the provinces of New Brunswick, Quebec, and Alberta.

In addition to the plants just mentioned, there are numerous jobbing concerns importing oils and greases in bulk and marketing them in smaller containers. Occasionally some of these do a little blending as well, but this phase of their work is negligible. Firms such as these are not regarded as producers, but rather as traders, and so no production records are obtained regarding their operations.

Statistics of production, imports, and exports of petroleum for a single year often present only a partial view of the subject. In an industry representing an investment of 50 to 60 millions of dollars, of which 12 to 20 million dollars represents the value of materials on hand and stocks in process, the variation in the quantities of stocks from year to year may be very considerable.

A very disturbing factor in petroleum refining operations in recent years has been the greatly increased production of crude oil in the United States. Many new producers there, marketing their products under highly competitive conditions, were compelled to sell their oil at a very low price, and refineries obtaining this cheap oil were able to put gasoline on the market at such reduced prices that many refineries in the United States, unable to meet this competition, were compelled to close down. Refiners there and in Canada, who had made long-term contracts for supplies of crude oil, were forced to meet the prices established by users of cheaper crudes, and, as a result, unit values of products sold in recent years do not bear the same relation to the cost of raw materials as was previously the case.

Increasing use of gasoline as a fuel for internal combustion engines—more particularly those in automobiles—is another factor that has had a most pronounced effect on the business of refining. The rapidly growing demand for motor fuel has stimulated the search for new supplies of crude but, better still, it has promoted the scientific study of motors and fuels, with a view to the conservation of presently available supplies, and already much valuable work has been done.

The production of gasoline in Canadian refineries has increased in recent years from 86 million gallons in 1919 to 165 million gallons in 1925. The value of the output did

not show as great an increase—production in 1919 was valued at 22.9 million dollars, and in 1925 at 27.6 million dollars. Thus, while the volume of production has been growing steadily, the decline in the unit price of the refined product, so noticeable in 1923, kept the value of the total output for that year close to the 1919 level and tended to retard the growth in production values.

Kerosene is still an important product; production averages about 50 million gallons annually.

Fuel and gas oils have been produced in much greater quantities during the past three or four years than formerly. In 1920, the output of fuel and gas oils from Canadian refineries amounted to 96.4 million gallons valued at 10.3 million dollars; in 1925 the output amounted to 172.3 million gallons valued at 9.6 million dollars.

Lubricating oils and greases, asphalt, wax, and candles, are other important products made in the oil refineries.

In the separation and purification of the various products obtained by the refineries in the treatment of crude oil, large quantities of sulphuric acid, caustic soda, and other chemical products are used. It appears that the consumption of 66° Be. sulphuric acid in petroleum refining is approximately one pound of acid to six gallons of crude oil; for caustic soda, the average seems to be about one pound to 100 gallons of oil. The consumption of containers, cooperage stock, etc., reaches large figures annually, even though some shipping containers used for oil are returnable.

Table 7 shows the products of the petroleum products industry in Canada, 1921-1925.

Canada's imports of crude petroleum for refining have almost doubled in the last five years. In 1920, Canada imported 291 million gallons of crude oil; in 1926, importations under this heading reached 570 million gallons. These figures alone give some idea of the tremendous development of the oil-refining industry in the Dominion during recent years.

Gasoline importations also are large, and the quantity imported is growing year by year, in spite of the fact that Canadian refineries are producing gasoline in larger quantities in each succeeding year. In 1920, Canada imported about

TABLE 7—PRODUCTS OF THE PETROLEUM PRODUCTS INDUSTRY IN CANADA, 1921-1925

	1921	1922	1923	1924	1925
Petroleum refining					
(a) Made for sale....$	48,247,834	53,274,180	42,749,716	46,258,331	47,383,459
(b) Intermediates made for use (chiefly as fuel) $	3,317,569	3,221,641	2,821,790	2,419,016	2,419,156
Lubricating oils and greases....$	1,367,012	539,742	709,028	733,720	959,512
Total....$	52,932,415	57,035,563	46,280,534	49,411,067	50,762,127

TABLE 8—IMPORTS INTO CANADA OF PETROLEUM, ASPHALT, AND THEIR PRODUCTS, 1920-1926

(Calendar years)

	1920	1921	1922	1923	1924	1925	1926
Asphalt....$	686,892	604,830	573,979	311,839	331,988	317,653	444,356
Petroleum oils, crude, fuel and gas $	28,635,249	23,819,384	24,697,612	21,701,012	24,433,529	28,362,277	35,388,395
Gasoline....$	2,404,488	7,611,458	8,760,924	7,160,632	9,344,153	11,599,629	11,958,795
Other refinery products....$	16,860,494	5,452,135	3,358,188	3,577,682	3,720,357	3,880,521	4,716,496
Total....$	48,587,123	37,487,807	37,390,703	32,751,165	37,830,027	44,160,080	52,508,042

56 million gallons of gasoline. Somewhat less than this amount was imported in each of the next three years, but in 1924 the total rose to 74 million gallons and in 1925 and 1926 the imports averaged about 84 million gallons.

Table 8 shows the imports into Canada of petroleum, asphalt, and other products in each of the past seven calendar years.

Consumption

On the subject of consumption, computed by adding production and imports and deducting exports of Canadian produce and re-exports of foreign produce, there are some interesting data in Table 9 on gasoline, kreosene, fuel and gas oils, and lubricating oils.

Financial Statistics

Canada's petroleum refining and blending plants numbered 21 in 1925, and represented a capital investment in lands, buildings, machinery, and general equipment amounting to more than 50 million dollars. The industry affords employment to approximately 4,000 persons, and the pay-roll approaches six million dollars annually. Purchased fuel and electricity cost about four million dollars a year, and purchased materials represent an outlay of approximately 38 million dollars annually. The selling value of refinery products is approximately equivalent to the actual investment in the industry, namely, about 50 million dollars. The value added by manufacturing, representing the difference between the selling value at the refinery of the products made and the cost of the crude oils and other raw materials used, is much less now than it was a few years ago, but it still amounts to upwards of 12 million dollars.

Table 10 presents a summary of the principal financial statistics of the petroleum products industry in Canada in each of the five years 1921-1925. Division is made as between the petroleum refining industry and the manufacture of lubricating oils and greases, which is essentially a blending proposition.

TABLE 9—PRODUCTION, IMPORTS, EXPORTS, AND APPARENT CONSUMPTION OF CERTAIN PETROLEUM PRODUCTS IN CANADA, 1920-1925

Year		Production	Imports	Exports	Re-exports	Apparent Consumption
Gasoline:						
1920	Imp. Gals.	86,193,664	8,515,545	160,433	214,643	94,334,133
	$	28,272,903	2,404,488	59,432	83,778	30,534,180
1921	Imp. Gals.	119,887,613	40,264,707	762,080	10,492	159,379,748
	$	31,026,136	7,611,458	212,638	3,917	38,421,039
1922	Imp. Gals.	143,959,893	42,112,248	1,976,244	27,620	184,068,277
	$	34,428,189	8,760,924	510,037	6,706	42,672,370
1923	Imp. Gals.	124,156,380	49,950,660	1,217,298	.....	172,889,742
	$	22,153,254	7,160,632	263,326	.....	29,050,560
1924	Imp. Gals.	160,245,739	73,757,441	1,403,716	75,223	232,524,253
	$	25,847,219	9,344,153	256,966	20,715	34,913,691
1925	Imp. Gals.	164,850,072	83,927,751	1,568,855	42,594	247,166,374
	$	27,638,537	11,599,629	333,330	11,788	38,893,048
Kerosene:						
1920	Imp. Gals.	54,155,655	14,971,509	1,243,335	.....	67,883,829
	$	10,887,972	2,359,621	205,999	.....	13,041,594
1921	Imp. Gals.	59,082,790	10,544,281	1,466,422	.....	68,160,649
	$	7,537,470	790,468	209,282	.....	8,118,656
1922	Imp. Gals.	76,521,560	3,673,234	1,471,947	.....	78,722,847
	$	9,628,804	314,514	136,834	.....	9,806,484
1923	Imp. Gals.	67,396,674	4,127,146	1,450,051	.....	70,073,769
	$	8,774,371	323,396	139,924	.....	8,957,843
1924	Imp. Gals.	61,328,467	5,431,393	1,525,427	.....	65,234,433
	$	7,490,442	447,588	165,520	.....	7,772,510
1925	Imp. Gals.	45,046,459	5,256,661	1,508,686	.....	48,794,434
	$	5,971,313	455,125	155,783	.....	6,270,655

Year		Production	Imports	Exports	Re-exports	Apparent Consumption
Fuel and gas oils:						
1920	Imp. Gals	96,462,792	122,929,391	2,684,427	.....	216,707,656
	$	10,341,946	7,819,006	293,325	.....	17,867,627
1921	Imp. Gals	129,716,045	61,398,671	5,384,751	.....	185,729,965
	$	6,611,261	3,805,714	375,820	.....	10,041,155
1922	Imp. Gals	106,975,976	72,805,012	7,036,627	.....	172,744,361
	$	6,142,927	3,091,290	288,828	.....	8,945,389
1923	Imp. Gals	139,682,570	108,982,780	2,384,899	.....	246,280,451
	$	7,973,766	4,245,101	138,381	.....	12,080,486
1924	Imp. Gals	177,123,232	94,244,271	18,263,236	.....	253,104,267
	$	9,076,746	4,133,208	529,497	.....	12,680,457
1925	Imp. Gals	172,387,242	107,849,209	7,375,163	.....	272,861,288
	$	9,652,255	4,918,279	346,512	.....	14,224,022
Lubricating oils:						
1920	Imp. Gals	25,099,798	4,464,294	.....	.....	29,564,092
	$	6,327,134	2,443,089	.....	.....	8,770,223
1921	Imp. Gals	24,246,320	5,040,456	.....	.....	29,286,776
	$	5,221,487	1,934,561	.....	.....	7,156,048
1922	Imp. Gals	18,051,600	7,110,054	.....	.....	25,161,654
	$	3,551,478	2,132,695	.....	.....	5,684,173
1923	Imp. Gals	17,121,896	8,196,682	.....	.....	25,318,579
	$	3,237,526	2,310,950	.....	.....	5,548,476
1924	Imp. Gals	15,479,465	8,494,423	.....	.....	23,975,888
	$	3,061,116	2,442,653	.....	.....	5,503,769
1925	Imp. Gals	15,789,852	8,445,738	.....	.....	24,235,590
	$	3,131,634	2,483,589	.....	.....	5,615,223

TABLE 10—SUMMARY STATISTICS OF THE PETROLEUM PRODUCTS INDUSTRY IN CANADA
1921-1925

Year	No. of plants	Capital employed	No. of employees	Salaries	Wages	Cost of fuel and electricity	Cost of materials	Selling value of products	Value added by manufacturing
Petroleum refining:		$		$	$	$	$	$	$
1921	11	55,630,864	3,911	724,045	5,279,514	4,429,308	35,850,653	51,565,403	15,714,750
1922	13	61,253,400	3,498	753,834	4,637,451	4,227,615	38,129,880	56,495,821	18,365,941
1923	14	60,288,861	4,196	816,751	4,714,818	4,054,846	36,435,306	42,749,716	6,314,410
1924	17	53,095,784	3,603	866,974	4,757,004	3,580,032	36,569,292	48,677,347	12,008,055
1925	13	49,461,900	3,655	913,688	4,708,210	3,433,017	37,814,303	49,802,615	11,988,312
Lubricating oils and greases:									
1921	5	1,933,724	103	112,825	66,130	10,343	778,923	1,367,012	588,089
1922	6	800,629	57	79,101	22,297	4,172	283,311	539,742	256,431
1923	6	738,843	62	93,628	23,123	6,236	381,390	709,028	327,638
1924	8	700,010	66	94,307	31,420	6,500	423,419	733,720	310,301
1925	8	1,118,649	83	101,252	51,896	14,113	446,721	959,512	512,791
Total:									
1921	16	57,564,588	4,014	836,870	5,345,644	4,439,651	36,629,576	52,932,415	16,302,839
1922	19	62,054,029	3,555	832,935	4,659,748	4,231,787	38,413,191	57,035,563	18,622,372
1923	20	61,027,704	4,257	910,379	4,737,941	3,897,272	36,816,696	46,280,534	9,463,838
1924	25	53,795,794	3,669	961,281	4,788,424	3,586,532	37,092,711	49,411,067	12,318,356
1925	21	50,580,549	3,738	1,014,940	4,760,106	3,447,130	38,261,024	50,762,127	12,501,103

NATURAL GAS

No records are available prior to 1892 as to the production of natural gas in Canada. An estimate of the value of gas produced during that year placed the total at $150,000.

The extensive developments of the oil fields in Ontario made available for consumption large quantities of natural gas. From 1892 to 1902, Ontario is the only province for which we have production records. In 1903, the first production from other provinces was recorded, when statistics were obtained of production in Alberta; but it is known that natural gas had been used for many years previously by the town of Medicine Hat, in Alberta, where it was first discovered by employees of the Canadian Pacific railway drilling for water at Langevin station, some 30 miles west of Medicine Hat.

New Brunswick's first contribution was reported in 1912. In Ontario, production has shown a gradually increasing value, but since 1918 the quantity produced has been declining year by year. On the other hand, the output from Alberta wells, which was maintained at fairly constant amounts between the years 1913 and 1924, has shown a very appreciable increase in the past two years, due largely to the growing output from the Turner Valley field, where the Royalite No. 4 well is located.

TABLE 11—PRODUCTION OF NATURAL GAS IN CANADA, BY PROVINCES, 1892-1926

Year	New Brunswick		Ontario		Manitoba		Alberta		Canada	
	M. cu. ft.	Value	M. cu. ft.	Value	M. cu. ft.	Value	M. cu. ft.	Value	M. cu. ft.	Value
		$		$		$		$		$
1892	.....	.....	.....	150,000	....	..	.....		.....	150,000
1893	.....	.....	.....	376,233	....	..	.....	.....	.....	376,233
1894	.....	.....	.....	313,754	....	..	.....		.....	313,754
1895	.....	.....	.....	423,032	....	..	.....	.....	.....	423,032
1896	.....	.....	.....	276,301	....	..	.....	.....	.....	276,301
1897	.....	.....	.....	325,873	....	..	.....	.....	.....	325,873
1898	.....	.....	.....	322,123	....	..	.....	.....	.....	322,123
1899	.....	.....	.....	387,271	....	..	.....	.....	.....	387,271
1900	.....	.....	.....	417,094	....	..	.....	.....	.....	417,094
1901	.....	.....	.....	339,476	....	..	.....	.....	.....	339,476
1902	.....	.....	.....	195,992	....	..	.....	.....	.....	195,992
1903	.....	.....	.....	196,535	....	..	.....	5,675	.....	202,210
1904	.....	.....	.....	253,524	....	..	.....	74,852	.....	328,376
1905	.....	.....	.....	316,476	....	..	.....	63,085	.....	379,561
1906	.....	.....	.....	533,446	....	..	.....	50,077	.....	583,523
1907	.....	.....	.....	746,499	....	..	.....	68,533	.....	815,032
1908	.....	.....	.....	988,616	....	..	.....	24,044	.....	1,012,660
1909	.....	.....	.....	1,145,307	....	..	.....	61,722	.....	1,207,029
1910	.....	.....	.....	1,271,303	....	..	.....	75,168	.....	1,346,471
1911	.....	.....	.....	1,807,513	....	..	.....	110,165	.....	1,917,678

Year	New Brunswick		Ontario		Manitoba		Alberta		Canada	
	M. cu. ft.	Value	M. cu. ft.	Value	M. cu. ft.	Value	M. cu. ft.	Value	M. cu. ft.	Value
1912	.....	36,549	.....	2,036,245	....	..	.....	289,906	.....	2,362,700
1913	828,603	174,147	12,474,745	2,055,768	....	..	7,174,490	1,079,466	20,477,838	3,309,381
1914	425,826	54,249	14,094,521	2,215,808	....	..	7,172,157	1,214,670	21,692,504	3,484,727
1915	430,692	60,383	15,211,523	2,622,838	....	..	4,481,947	1,022,814	20,124,162	3,706,035
1916	610,118	79,628	17,953,109	2,765,105	....	..	6,904,231	1,113,296	25,467,458	3,958,029
1917	796,775	103,735	19,868,035	3,641,587	....	..	6,744,130	1,299,976	27,408,940	5,045,298
1918	792,396	107,842	13,029,524	2,884,460	....	..	6,318,389	1,358,638	20,140,309	4,350,940
1919	682,890	120,510	11,024,041	2,690,400	....	..	8,230,838	1,365,127	19,937,769	4,176,037
1920	682,502	130,506	10,529,374	2,920,731	200	60	5,633,442	1,181,345	16,845,518	4,232,642
1921	708,743	139,375	8,422,774	3,080,130	200	60	4,945,884	1,374,599	14,077,601	4,594,164
1922	753,898	148,040	8,060,114	4,076,296	200	60	5,868,439	1,622,105	14,682,651	5,846,501
1923	640,300	126,068	8,128,413	4,066,244	200	60	7,191,670	1,692,246	15,960,583	5,884,618
1924	599,972	113,577	7,150,078	3,798,381	200	60	7,131,086	1,796,618	14,881,336	5,708,636
1925	639,235	122,394	7,143,962	3,958,006	200	60	9,119,500	2,752,545	16,902,897	6,833,005
1926*	675,463	133,740	7,400,000	4,200,000	200	60	10,500,000	3,507,000	18,575,663	7,840,800
Total	†9,267,413	1,650,743	†160,490,203	57,798,367	1,400	420	†97,416,203	23,203,672	†267,175,229	82,653,202

*Estimate.

†Total quantity produced 1913 to 1926.

INTRODUCTORY REMARKS AND DISCUSSION

THE CHAIRMAN (MR. J. A. H. CHURCH): Mr. Ness is unable to be present, but he has sent us a written introduction to the discussion, which I will read to you. It is as follows:

MR. JOHN NESS (Canada): First we have Sir Thomas Holland's contribution, "Conditions Affecting the Petroleum Prospects of the Empire". The text of this able exposition of International economics is found in these words: "The British Empire contains a wider variety of minerals than any other national unit; and, whilst it has an exportable surplus of some that are essential, its requirements of others exceed its own production; of this latter class petroleum is about the most important".

After reviewing the American viewpoint on world distribution of oil resources and pointing to the supreme importance of petroleum as a factor in national and international affairs, inasmuch as the interests of the large oil companies and their several governments roughly coincide, the paper questions whether government officials or officially supported bodies are the proper mediums for the publication of views regarding the probable trend of any mineral industry, their status adding a weight of responsibility which must militate against a free expression of opinion, and cause their pronouncements to follow, rather than to advocate, technical or other development.

Sir Thomas looks upon this Congress as an opportunity to discuss whether the time is not now ripe for undertaking an estimate of the conditions affecting the development of petroleum within each self-contained unit of the Empire, and, therefore, the Empire as a whole.

By a resolution adopted at Montreal, Congress has referred to the constituent Institutions considerations of the formation of special non-official 'watch' committees, leaving each Dominion to work out for itself its own particular problems of mineral supply and demand, and, for the guidance of such committees, he lays down six general propositions which might aid in focussing discussion and formulating a general Empire policy on petroleum.

The "Economics of the Petroleum Situation in British Dominions" is discussed by Sir Frederick Black, the keynote of whose contribution is realization of the fact that the natural petroleum question is only a part, although perhaps the most important for the moment, of a general fuel problem.

After elaborating the British viewpoint, as laid down by Sir John Cadman, and the American conception, as presented by George H. Jones of the *Standard* of New Jersey, as to the prospects of a continuance of oil supplies, he arrives at the conclusion that the happy mean is a sane optimism tempered by eternal vigilance and activity.

With this assurance Sir Frederick Black considers the problem of most immediate interest to the Dominion as being the necessary movement of oil products and the possibility of the disruption of the existing arrangements by wars or new tariff conditions.

"Petroleum Refining Facilities within the British Empire" are reviewed by Mr. Jas. McConnell Sanders, who surveys the position of the Empire if called upon to not only produce but also refine all its needful petroleum products.

He shows the total refining capacity as about sufficient to handle 7 to 8 million tons of crude divided as follows: Great Britain and Canada, 2⅓ million tons each; India, 1¾ millions; Sarawak and Trinidad, about ½ million tons each.

As the total consumption of petroleum products in the Empire amounts to about 10 or 11 million tons, whilst its output of crude is only about 3 million tons, we are not only dependent on outside sources for three-quarters of our normal requirements but have still insufficient refining capacity even were an adequate crude supply developed.

Mr. Sanders not only deals with crude supplies, but discusses our resources in all material entering into the refining industry and finds the Empire fairly well equipped. He also is optimistic regarding the steps taken since the war for the training of petroleum technologists, whether in the geological, engineering, or refining side of the industry.

Mr. E. H. Cunningham Craig, who treats with the "Progress and Prospects of Oil Production", groups the various areas into:

A.—Producing fields
B.—Oilfields or supposed oilfields, prospected but not producing
C.—Fields containing retortable material

He sees in the producing fields many years of usefulness, with a probable increase in production from Canada, Sarawak, Trinidad, and probably Assam.

Regarding areas prospected or being prospected he is not so enthusiastic, although he has a kind word for Canada, British North Borneo, and New Guinea. His chief hope for the future appears centred on the areas containing retortable minerals, and he visualizes a substantial addition to the Empire's resources from the cannels, torbanites, oil shales, lignites, and tar-sands in Great Britain, Canada, South Africa, and Australia.

Even with this assistance we will fall far short of our requirements, but, with the help of Persia, Mr. Cunningham Craig considers it should not be impossible to keep every dominion, colony, or dependency supplied, and retain a margin in time of emergency.

Mention might be made of Mr. Alfred Nash's paper on "Possible Auxiliary Sources of Liquid Fuels", submitted at the Quebec session of this Congress, the conclusion of which is that with crude petroleum at its present price practically none of the methods he outlines would appear to be financially possible; but with enhanced crude prices, due to exhaustion of world supplies or temporary shortages owing to wars, all the processes dealt with might provide an adequate and valuable supply of liquid fuel and be financially successful.

Coming now to "Petroleum and Natural Gas in the Dominion of Canada", we have to acknowledge the assistance which made possible the presentation of a series of papers by those who "speak with authority and not as the Scribes", especially the scribes of Oildom.

As a result, Congress is fortunate in having placed before it a review of the Dominion's petroleum resources which can safely be termed both impartial and authoritative, the various authors being peculiarly fitted to deal with their particular subjects, and their conclusions being presented in a manner which bespeaks for them that consideration and attention which every honestly expressed opinion merits.

Petroleum development being a progressive science, however, it is only to be expected that, since these papers were written, the march of events in the field may have amplified or modified the data presented.

These several papers are now left to your tender mercies.

The Congress, as a body, is careful to clear its skirts of all responsibility for the statements and opinions expressed in any of the publications; but, as the individual charged with the duty and privilege of bringing these papers to your attention, I feel safe in commending them to your most serious consideration and contemplation, being convinced that the authors have presented their views in an exceptionally fair and straightforward manner.

MR. J. A. MILES (England): There are one or two matters in connection with the paper introduced by Sir Frederick Black which I think might be of interest and which have a great bearing, I think, on the question of production and consumption of petroleum in the near future.

There is one very interesting point put forward by the Committee which was appointed in the United States of America in 1923. It says that if fifty per cent increase in population in the United States in the next fifty years was allowed for, and the saturation point of motor vehicles was taken at *one per family*, there would be such an enormous increase in the number of motor cars in the United States at that time, that there would appear to be quite a good outlook both for the manufacturers of motor cars and for the petroleum companies!

Sir Frederick Black also alludes to the fact that you can find kerosene oil in use everywhere. Those of you who come from the East well know that in every village in India, in China, and in practically every village throughout the East, thanks to the organisation of the great oil distributing companies, kerosene is to be found in general use. Whilst we at home, and in a large measure those in the United States, look upon motor spirit as being the principal article of consumption, it must not be forgotten, when the question of production and consumption is considered, the enormous demand that exists for kerosene in the East. I spent ten years in India, and I

know that with the improvement in the standard of living in the East there will be a still greater demand for kerosene, and I may say for 'light', to the benefit of civilisation.

Sir Frederick also points out the very great advance that has been made in motor transportation in the East, apart from the enormous demand which exists in the United States and the United Kingdom today for petroleum spirit. There is undoubtedly also a great demand growing up in the East for motor transportation purposes. Whilst the bullock cart is still being largely used, motor cars are now being utilized on the desert routes from Damascus to Baghdad, from Algiers and Tunis far down into the Sahara, and I have reason to believe that it will not be so very many years before the demand for motor vehicles in India and in the East—not so much China on account of the difficulties of transportation there—will be enormously increased. I think these are points, gentlemen, in which you might be interested.

DR. G. S. HUME (Canada): Mr. Chairman, during the past summer I visited the oil fields of Alberta, and since the Congress party was prevented, on account of the weather, from visiting Turner Valley, I propose to tell you something about the recent developments there, which Dr. Hopkins was unable to cover in his paper.

The most important development in Turner Valley during the summer was the bringing-in of Dalhousie No. 5 well. The sand from which the oil comes is a siliceous sandstone of compact appearance, and to date no tests of the porosity it contains have been made. The crude oil that was obtained has a gravity between 40 and 50 degrees Beaumé, and it is thought to be coming from the same horizon which is productive in Home No. 1 well. When the well came-in it flowed by heads, and various estimates of the flush production, up to several hundred barrels per day, were made. We do not know, however, what the production will be, although a test was reported to have been made the day the Congress left Calgary.

The Dalhousie No. 5 and Home No. 1 wells are both in the southern part of Turner Valley and they have opened up new possibilities for production there. No wells in this part of the field have as yet reached the deeper horizon that is giving the production of 600 barrels of naphtha per day in

Royalite No. 4 well. The age of this lower productive horizon has been difficult to determine but it is undoubtedly Palæozoic and probably Pennsylvanian, and supposedly it correlates with the Rundle limestone of the Banff area.

In addition to the two productive horizons already mentioned, several sands in the Lower Cretaceous formations are productive in Turner Valley. There is, however, no production from the base of the Colorado shales which, in the Plains area, consists of alternating sands and shales and yields oil as well as gas in a number of fields.

In the Wainwright field, which we will visit, there are two productive horizons. The upper of these is believed to be in the sands at the base of the Colorado shales and the lower is presumably Lower Cretaceous.

SIR ALBERT E. KITSON (Gold Coast): Mr. Chairman, I should like to say a few words. The remarks of the last speaker are very interesting to me and have explained one or two points that were not clear to me. On the Eastern side of the Rockies we have an extremely important area which Nature has provided for Alberta especially and for Canada generally. Since that great range on the West owes its origin largely to uplift and over-thrust after great pressure from the West, the comparatively young coal of Alberta has been so compressed as to get the character and composition of much older coals. These great dynamic operations may also have had some influence upon the formation of gas and oil in the Foot Hills region. The three areas comprising Bow Island, Viking, and Battle River, all seem to offer possibilities for the future, and I think it is quite likely that when further investigations have been made something more of value will be found.

It would also seem that we have here a flow of gas, containing helium. Northwest of Toronto, in very much older rocks, we have a most interesting occurrence. It is the only source in the Empire from which we can get helium in comparatively large quantities, and it is to be hoped that we shall find more in Canada, so as to supplement our resources of that useful gas.

In connection with the oil-bearing sands of Alberta there does not seem to be any doubt of their use for road-making.

I remember on a trip in 1924 seeing a plant where they were extracting bitumen from the sand with a view to using the bitumen for various purposes, but here they seem to have struck a new idea and an extremely important one, for we are told that the Alberta oil-sands are simply brought here, treated and mixed with other sand and used to make the surface of this road. Well, all of us who have travelled on this road can see how effective this has been in making a good surface, and there seems to be a strong possibility that we are going to get a very large market for all the huge deposits of bituminous sands that Alberta has available.

POSSIBLE AUXILIARY SOURCES OF LIQUID FUELS

By Alfred W. Nash (*Member, Inst. Petr. Tech.*)*

(Quebec, Que., Meeting, September 5th, 1927)

The essential need of an internal source of liquid fuel to a belligerent nation was demonstrated beyond question during the Great War, and the motive which is now urging on the greater nations of the world to seek for some cheap substitute for petrol or other liquid fuel from their own resources is undoubtedly a desire to be independent of foreign supplies which might be curtailed or completely cut off, not by failure of natural sources, but by war-time conditions or due possibly to political pressure. The development of the Diesel engine both for stationary and marine purposes, and possibly in the future for light vehicles both on land and in the air, together with the increase in the development of power generally, will cause a greater demand for crude oil in the future. Although this demand will be met, undoubtedly, by the petroleum industry as the occasion arises, it nevertheless gives cause for serious consideration to a country which depends practically entirely on supplies from overseas.

Power alcohol.—The amount of alcohol used to drive internal-combustion engines is small compared with gasoline but varies considerably in different countries. Fermentation processes for this depend largely on the possibility of obtaining fermentable substances as by-products in other industries. An example is the production of alcohol from waste liquors from the treatment of wood by the sulphite process. Germany, Norway, and Sweden are countries in which this particular waste product is used.

In Great Britain, however, a process of this kind appears to be impracticable owing to the lack of sufficient raw material.

A further source of alcohol is from the reduction of acetaldehyde formed by the catalytic combination of acetylene and

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water. This process is carried out by the Lonza Company, but has been abandoned in Great Britain on commercial grounds. The cost of calcium carbide is the important factor of the process.

The production of alcohol by the absorption of ethylene from coal gas and coke oven gas in sulphuric acid was at one time thought to be promising, but the reconcentration of the acid has been found to be a greater expense than the process could bear. A further development has been made recently—namely, the neutralizing of the sulphuric acid with ammonia, thereby yielding ammonium sulphate and freeing the alcohol, which would appear more hopeful.

Ethyl alcohol as a fuel for internal-combustion engines is only equivalent to three-quarters of its volume of gasoline, yet mixtures have been shown to be quite satisfactory fuels. Natalite, a mixture of 40 per cent ether and 60 per cent alcohol with about 0.5 per cent castor oil could be quoted as an example, and for this fuel a slightly larger carburettor jet is necessary. To obtain the maximum number of miles per gallon with alcohol the compression ratios of the present-day type of engines would need to be increased.

The Power Alcohol Committee of the Ministry of Agriculture and Fisheries (1926) ([1]) have shown that since alcohol has a much lower vapour pressure (at atmospheric temperatures) than either petrol or benzol, starting difficulties will be experienced. So low indeed is the vapour pressure of ethyl alcohol that it requires a temperature of 25°C. (77°F.) to form the weakest explosive mixture at atmospheric pressure.

Ricardo points out that the temperature at which starting is possible would be appreciably lowered by the presence of 10 to 16 per cent of ether in the alcohol mixture. With such a small proportion of ether, however, it is not possible with most carburettors to start the engine from cold. Alcohol is a very clean-burning fuel, and in this respect greatly superior to benzol.

Oil Shales, Torbanites and Tar Sands.—The search for oil shale and similar bituminous materials has not been prose-

([1]) Report on Power Alcohol Production—Ministry of Agriculture and Fisheries, 1926, p. 4.

cuted with any great seriousness up to the present; nevertheless, it is known that deposits exist in practically every country in the world. Whilst having one characteristic in common, in that the oils they yield do not exist in the inorganic material as such, but are the result of decomposition of the organic matter, various oil shales behave quite differently on distillation, and it is not suggested therefore that all difficulties connected with their commercial utilization have been overcome. Certain problems, which are chiefly technical, still remain, but the past history of the Scottish oil-shale industry affords an excellent example of how these technical difficulties can be solved when the necessity arises.

Tar sands have been mentioned because of their particular interest to those concerned with petroleum in Canada and also in view of their potential value, if only as cracking stock.

The tar sands of northern Alberta, more commonly known as the Athabaska tar sands, consist of asphaltic material mixed with sand of varying degrees of fineness. These sands contain from 7 to 20 per cent by weight of recoverable oil, and this, when extracted by superheated steam, resembles a soft, sticky pitch containing a considerable amount of water in suspension, with a varying sulphur content up to about 4.5 per cent. As a fuel oil it is useless in its natural state owing to its being so extremely asphaltic and viscous—being practically solid at ordinary temperatures.

These tar sands are situated on the Athabaska river about 300 miles north of Edmonton, and whilst the extent of the deposit is not yet definitely known, they are said to cover an area of several hundred square miles. The east bank of the river is practically a continuous outcrop of the bituminous sand for a distance of about 60 miles, in some places reaching a height of 200 feet: the overburden in that portion of the area which has been investigated varies from a few feet to 200 ft. in thickness.

Three methods have been proposed for the utilization of these bituminous sands:

(*a*) The separation of the oil and sand by washing with a dilute solution of a salt which is capable of reducing the

surface tension of the water in suspension, followed by hot-water flotation.

(*b*) The 'topping' of the bituminous sand in closed retorts, similar to the methods employed in the destructive distillation of oil-shale.

(*c*) Mixing of the bituminous sand in its natural state with additional sand or crushed limestone for use as a paving material.

A further method has been suggested, but as it has not yet developed beyond the experimental stage, it is impossible to express any opinion as to its practicability. It consists of drilling holes in the ground into which are lowered two pipes, one within the other: steam is blown down the annular space at pressures up to 200 lb. to the square inch and enters the sand through perforations at the bottom.

The oil which collects at the bottom of the sump is blown up the centre tube by means of the steam pressure and fractional separation takes place at the surface.

As already stated no opinion can be expressed as to its commercial application, but in view of the fact that the natural bitumen is so extraordinarily unstable when heat is applied, which will be shown later, it would appear that providing sufficient heat is conveyed to the sand, the problem of extraction is not only a lowering of the viscosity of the tar by physical means, but also probably partial decomposition, and theoretically would appear feasible, although the separation of the resulting emulsion would present some difficulty.

For the purpose of this paper schemes (*a*) and (*b*) only will be considered in detail.

From the point of view of refining, the first suggestion would not appear to be so satisfactory as scheme (*b*). For instance, the density being from 1.018 to 1.022, great difficulty is experienced in freeing the oil from the water, and even after this is done as far as possible by preliminary heat treatment, excessive frothing due to the suspended water has been found to occur on distillation.

The natural oil obtained by separation has the following characteristics(1):

Solvent	Per cent soluble	Nature of residue
Carbon disulphide.....	100 ..	
Carbon tetrachloride....	100 ..	
Chloroform.....	100 ..	
Benzene.....	98 ..	black solid
Ether (hot).....	86.9 ..	brown solid
Acetone (hot).....	70 ..	brown solid
Alcohol (hot).....	33 ..	brown solid
Sulphuric acid, conc:....	100 (after several days)	
Nitric acid, conc:.....	100 (after several days)	

An oil emulsion separated by flotation has been examined in our own laboratories by heating in an oil bath in a stream of nitrogen to 200°C. The distillate obtained (25.9 per cent) was chiefly water.

The oil residue in the flask was then transferred to a Fischer aluminium retort and distilled to 450°C., yielding 63.8 per cent of oil and 26.5 per cent of coke: distillation of a second portion gave 65.3 and 23.7 per cent of oil and coke respectively. The oil was fluorescent, mobile and gummed on standing.

To this was added the small smount of oil which had distilled over with the water in the stream of nitrogen and the whole was labelled 'crude distillate.'

Distillation of the *crude distillate* in an Engler flask (100 c.c.) standard I.P.T. conditions, gave the following results:

I.B.P. 60°C.

I.B.P. 60°C.		
Fraction to 175°	..	7 per cent by vol.
175—225°	..	9 " " " "
225—300°	..	18 " " " "
Above 300	..	66 " " " "

Sulphur content:

Crude distillate	2.98 per cent
Fraction to 175°C,	1.64 " "
175—225°	2.61 " "
225—300°	2.75 " "
Above 300°	3.38 " "

(1) *Journ. Am. Chem. Soc.*, 1921, **43**, 1337.

Comparison with Trinidad and Bermundez asphalt (*loc. cit.*) shows the Alberta bitumen to have a greater oily and resin content, but the percentage of asphaltenes is lower:

	Alberta	Trinidad	Bermundez
Saponifiable matter	2.0	10.3	5.5
Asphaltenes	22.5	37.0	35.0
Resins	24.0	23.0	14.4
Oily constituents	51.5	31.0	39.6

Its ultimate composition is: S, 2.73 per cent; C, 84.49; H_2, 11.23; N, 0.04.

The second scheme (*b*) would appear to offer better possibilities, in view of the peculiar chemical nature of the bitumen.

Distillation of the bitumen without decomposition is impossible at atmospheric pressure, as cracking takes place below 100°C., and even under considerably reduced pressure cracking begins at 150°C. After separation from the sand the tar, freed from asphaltenes and petroleum resins by Marcusson's method, was found to have the following characteristics (*loc. cit.*):

d^{20}	0.927	Sulphur	1.87
n^{20}	1.500	Carbon	85.76
Opt. activity dextro	1.5—1.6	Hydrogen	12.19
Viscosity at 25°C	20.0		
Molecular weight	350.0		

The distillate above 100°C. possessed a red colour and a rank odour whilst that below this temperature was a clear colourless limpid oil with a strong turpentine odour.

All distillates, although only slightly unsaturated, dissolved completely in concentrated sulphuric acid, whereas the loss with liquid sulphur dioxide was only 1 per cent, when all disagreeable odour was removed.

From the result of combustion, substantiated by molecular refractive power, it was concluded that the three series of hydrocarbons present were C_nH_{2n}, C_nH_{2n-2}, and C_nH_{2n-4}.

As the molecular refractive index and the molecular volume indicate no unsaturation, the suggested structures of these hydrocarbons are in the case of the C_nH_{2n-2} series, either two phenyl groups linked together with the appropriate

number of methyl or ethyl radicles, or of the saturated naphthalene type; in the case of the C_nH_{2n-4} compounds, tricyclic; and with the two of the C_nH_{2n} compounds, naphthenes with methyl groups attached.

The commercial products obtained by the distillation of the bitumen from the bituminous sand are as follows(1):

Refined products	45 per cent
Gas	5 "
Ref. Losses	20 "
Pitch	5 "
Coke	25 "

Distillation range of the *crude distillate* obtained by retorting:

	per cent		per cent
70°—150°C	9.7		
150°—230°C	9.1	Water by vol	3.2
230°—260°C	4.9		
260°—300°C	13.3	Sediment	0.5
300°—325°C	18.6		
325°—350°C	14.0	Oil by vol	96.3
350°—380°C	23.0		
Residue and loss	7.4	Sp. Gr	0.937

The *crude distillate* therefore should make a good fuel oil and in view of Mabery's work regarding the value of the above hydrocarbons for lubricants it is possible that the lubricating fraction (provided these compounds remain unchanged), said to be about 50 per cent of the *crude distillate* (*loc. cit*), might be first extracted from the lightly topped oil, and the balance used for cracking stock, although coke formation would appear to be a difficulty.

In refining the lubricating fraction, a physical method would undoubtedly be necessary; whilst a proportion of the sulphur content would be eliminated during distillation in the form of sulphuretted hydrogen, nevertheless the sulphur question is one to be considered in view of the possibility of corrosion in the distillation plant.

With regard to the possibility of cracking Alberta bitumen the following preliminary experiments, carried out in our laboratories, are of interest.

(1) *S.I.R.C.*, Alberta. 2nd Annual Report, p. **54**, 1922.

A sample of bitumen, largely freed from water, as described previously, was divided into two portions; one was submitted to cracking in an atmosphere of nitrogen, and the other hydrogenated under Bergius conditions. In the cracking experiment no initial pressure was employed and the temperature was taken up to 450°C., and maintained there for an hour. Pressure developed during the heating. In the case of the hydrogenation an initial pressure of 46.4 atmospheres of hydrogen was used; time and temperature conditions being similar to the cracking experiment.

The experimental results, yields of distillates and bromine values (McIlhiney) are tabulated below, and compared with the fractions obtained by direct distillation of the bitumen from the Fischer aluminium still.

As these experiments have only just been commenced the results are put forward as tentative only, as the optimum conditions for both cracking and hydrogenation have not yet been worked out. They tend to confirm, however, the view already put forward regarding the difficulties likely to occur from coke formation under cracking conditions.

Experiment	Pressure in atm.			Yields % on dry bitumen		
	Init.	Max.	Final	Oil	Coke	Gas and loss
Cracking (1 hr. at 450° C.) Bitumen: Water 2.7%, ash and suspended matter 3.5%	1	78.4 at the max. temp.	15.5	41.3	29.0	29.7
Hydrogenation (1 hr. at 450°). Bitumen: Water 4.6%, ash and suspended matter 6.0%	46.4	131.5 at the max. temp.	38.6	50.5	21.6	27.9
Direct distillation..... Bitumen: Ash and suspended matter 4.87%	—	—	—	62.4	22.5	15.1

Experiment	Engler distillation of oils; percentage volume			Percentage volume of distillates on volume of original bitumen		
	Cracking	Hydrogenation	Direct distillation	Cracking	Hydrogenation	Direct distillation
I.B.P.....	50°C.	42°C.	66°C.	—	—	—
Fraction up to 175°	38.8	42.5	7.0	18.2	21.1	4.8
175—225°.....	15.6	15.0	6.0	7.3	7.4	4.1
225—300°.....	21.2	20.0	21.0	9.9	9.9	14.4
Above 300°....	24.4	22.5	66.0	11.4	11.1	45.2

Bromine Values (McIlhiney) and Loss to Sulphuric Acid

Experiment	Fraction to 175°C.				175—225°C.			
	Br. value.		Loss to 80% H_2SO_4	Loss to 98% H_2SO_4	Br. value.		Loss to 80% H_2SO_4	Loss to 98% H_2SO_4
	Subs.	Addn.			Subs.	Addn.		
Cracking	10.14	28.89	No appreciable loss but charring in H_2SO_4	20%	15.28	9.27	No appreciable loss but charring in H_2SO_4	60%
Hydrogenation	8.27	17.08	No appreciable loss but charring in H_2SO_4	15%	12.31	5.31	No appreciable loss but charring in H_2SO_4	65%
Direct distillation	10.97	52.08	No appreciable loss but charring in H_2SO_4	35%	14.87	34.03	No appreciable loss but charring in H_2SO_4	35%

Turning now to more advanced methods of motor fuel formation, it should be mentioned that certain countries in Europe are especially concerned with the production of lubricating oils and fuels for internal and external combustion as,

so far as can be judged at present, they do not appear to have been so liberally endowed by nature as is the case in other parts of the world; consequently an impetus is given for the investigation of substitutes for these commodities from other raw materials.

In this country and in Germany, coal is looked to for this purpose, one reason for its use being the over-production, particularly of coal of inferior value and sortings, and it is certain that we must look upon this material as the national reservoir of fuel oil for use in case of emergency even if it cannot profitably furnish this commodity in normal times.

Three methods will be considered in the following order, although, as will be seen later, the first and last can be worked together.

(*a*) Low-temperature carbonization of coal.
(*b*) Berginisation.
(*c*) The conversion of water into liquid fuels.

LOW-TEMPERATURE CARBONIZATION

Much attention has been given to this problem both in Great Britain and on the Continent; indeed, Germany has been carbonizing her younger coals for some years now with considerable success. The problem so far as this country is concerned is not quite the same, however, because of the marked difference in composition of our bituminous coals compared with coals largely used in Germany for this purpose, and consequently the marked difference in the products obtained.

Nevertheless the known main natural source of energy in this country at present, excluding the sun, and for that matter of the World, is coal, the located deposits of which exceed many times those of any other kind of natural fuel. Coal is the chief storehouse of our unrealized natural wealth and whilst most people regard it solely as a fuel, scientists are anxious that it should be treated as a raw material from which fuel, amongst many other things, may be obtained.

High temperature carbonization of coal has been working successfully for many years, and the tar derived therefrom is known to contain between 300 and 400 substances of which

about half have been isolated and can be divided into classes—neutral, acidic or basic; the number of tar derivatives obtainable is well over 2,000.

Low temperature carbonization is still in its infancy, and the value of the tar obtained thereby is at present unknown: fractionation by distillation is no guide whatsoever, excepting as a measure of volatility.

Statements have been made to the effect that it is impossible to 'crack' low temperature tar successfully and so obtain an increased yield of motor spirit, but such views should be accepted with caution, as sufficient experimental evidence has not yet been forthcoming to enable a definite opinion to be expressed. Tars from different coals and from different methods of retorting varying to such a considerable extent, and our knowledge of this material being so slight, it would be dangerous to dogmatise on any such point. Coke formation would appear to be one great difficulty.

In regard to low temperature carbonization generally, it should be mentioned that in Great Britain over 200 processes have been put forward in various stages of evolution: of these from ten to fifteen have reached what might be described as the technical stage, but only three or four methods have grown to the really large scale stage of development. The chief drawbacks would appear to be our lack of knowledge of the thermal conductivity of coal and its behaviour under carbonizing conditions, either in the raw or fluid state; and the losses due to the powdering of the semi-coke, which vary considerably with the method of retorting, and invariably exceed 10 per cent. The last difficulty might be overcome by a process which will be suggested later.

As already indicated, the yields of the various products may differ, as do the chemical and physical properties of the tars obtained, according to the coal used, the conditions under which the tars are prepared and the type of retorting system employed, but true low temperature carbonization yields roughly about 14 cwt. of semi-coke, 14 to 20 gallons of water-free tar, and from 3,000 to 5,000 cubic feet of gas, from one ton of coal. The tar would yield about one and a half or two gallons of light oils, while about one and a quarter gallons of light spirit can be extracted from the gas by scrubbing.

So long as the tar production is looked upon as the primary product in normal times, low temperature carbonization will never develop in this country; the production of smokeless fuel must be the chief object and the production of liquid fuel considered of secondary importance: in other words a by-product. Further, it is very doubtful, excepting in a few isolated cases where higher temperatures are used and depending largely on the type of coal carbonized, whether the yields of sulphate of ammonia will ever reach more than a few pounds per ton, and in true low temperature carbonization the extraction of the ammonia will prove to be a definite loss.

The value of low temperature tar will also depend on its suitability as a source of pure chemical substances, a problem on which several chemists are at present working.

In their study of the tars and oils produced from coal, Sinnatt, King and Linnell ([1]) have given some interesting experimental evidence regarding the behaviour of low temperature tars obtained under varying carbonizing temperature conditions ranging from 400° to 700°C. In the carbonizing unit used([2]), the rate of heating of the coal was slow at 400°C., increasing at higher temperatures: gas, water and tar evolution rates for each temperature were plotted against time and the results are of extreme importance to those interested in this problem.

Briefly, the maxima for tar and gas production were found to coincide approximately up to a temperature of 550°C., whilst at 660° the peaks extended over a longer interval; above this temperature they diverge, the gas maxima occurring later than those of the tar.

The yield of tar examined increased to a maximum at 550°C. retorting temperature and then decreased steadily, such yield at this temperature being 17.65 gallons per ton, or 67.7 per cent. of the yield obtained by laboratory apparatus which might be described as the theoretical. Steady increase in specific gravity took place with increasing temperature, but above 550°C. the increase was accelerated. The temperature of 550° C. therefore would appear to be a critical one as

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([1]) *J. Soc. Chem. Ind.*, 1926, **45**, 385T.
([2]) Report of F.R.B. 1920–21, Section 1.

secondary decomposition at the expense of the tar was demonstrated by the increasing specific gravity and gas evolution above this point.

For three reasons the study of the aqueous distillate from low temperature carbonization is essential; first, because it contains organic compounds, especially phenols; secondly, because of the possibility of the vapour and distillate affecting the condensing plant; and lastly, in view of the probability of the liquor having to be disposed of as an effluent.

In this investigation the aqueous distillate was found to be acidic (a matter of considerable importance from the practical standpoint) at lower temperatures due to the presence of hydrochloric acid, at 500° to 550° neutral, and above this temperature it was alkaline due to ammonia. The amount of ammonia present did not appear to warrant its recovery as ammonium sulphate.

The special tars from the different carbonizing temperatures were examined, and it was found that the lighter fractions—*i.e.*, up to 230°, increased in amount to a maximum at a carbonizing temperature of 550°. Above this temperature they decreased rapidly at first and later more slowly: the middle fraction increased rapidly in amount to a maximum at the same temperature and then decreased. Increase in the amount of the lightest fraction was even more rapid than that of the middle fraction, but it did not reach a maximum until a carbonizing temperature of 550° was reached.

These changes were accompanied by continuous increases in the amount of pitch formed, with marked acceleration as the carbonizing temperature rose from 500° to 550°. Decomposition occurred with the 400° tar at 345°C., with the 650° tar at 325°C., and the 700° tar at 330°. The 450°, 500°, and 600° tars were each distilled to 360°C. Under a reduced pressure of 20 mm. the distillates obtained coloured more rapidly on keeping than did those obtained at atmospheric pressure.

Whilst the pitches did not receive exhaustive examination it was found that they increased in hardness with rise in carbonization temperature. Those obtained from tars produced at 600° and 650° were abnormal, as they fractured when allowed to cool in bulk and were extremely brittle. The

550° pitch exhibited this property also to a lesser degree, whilst that from 700° tar, although showing no tendency to fracture on cooling, was nevertheless hard and brittle.

After removal of the phenols and bases, the neutral oils were thoroughly washed with slowly increasing strength of sulphuric acid to prevent as far as possible the decomposition of the unsaturateds.

Changes in the main constituents due to any critical temperature of carbonization was not marked: the phenols were about 29 per cent in the 450°, 500° and 550° tars, and then began to increase. The amount of unsaturated compounds also showed an increase abouve 550°—*e.g.*, in the 400° tar the proportion of unsaturated oils was 44 per cent, and saturated oils 29.8 per cent; in 700° tar unsaturated oils were 52.2 per cent, saturated oils 6.2 per cent. An appreciable proportion of the saturated oils produced at low temperatures was wax, but solid paraffins were found in oils produced by carbonization at a higher temperature than 600°.

The weights of the fractions obtained by the distillation of the crude oils, the neutral oils and the saturated oils were summarized by the investigators as follows:

(1) The removal of the relatively large proportions of phenols from the middle fractions increases the proportions of the lighter fractions in the neutral and saturated oils. This effect is similar for all oils, and the middle fractions are correspondingly reduced.

(2) The residues remaining after the final temperature of 354° is reached are approximately the same in each case for crude and neutral oils. The proportions are about 5 per cent and 9 per cent for the 400° and 450° oils, rising to a maximum of about 15 per cent for the 550° and 600° and decreasing again to 9 per cent and 5 per cent for 650° and 700° oils. The residue obtained when the saturated oils are distilled is considerably greater, but shows the same variations rising from 16 per cent in the 400° oil to a maximum of 30 per cent in the 600° oil and falling again to 20 per cent in the 700° oil.

A tar produced on a large scale from a unit of two vertical retorts capable of dealing with 4½ tons per day was examined in a similar manner to that just described. The coal used

was Dalton Main, which yielded 15.14 cwt. of smokeless fuel, 5,188 cu. ft. of 719 B.T.U. gas and 16.7 gallons of tar $d\ \frac{15}{15} = 1.050$, this tar yield being 61 per cent of that obtained from an assay experiment. The tar was found to be substantially similar in characteristics to that previously described.

In a previous paper by the Author and another([1]) a statement was made to the effect that the tar from carbonized coal could never replace natural petroleum in normal times, because it was not only of poorer quality, but the variety of products for the purpose in mind was very limited—*e.g.*, lubricants, vaseline, asphalt, etc., were missing, and there was a very high percentage of low-quality pitch left as residuum; also that low-temperature tar, when subjected to ordinary distillation, yielded an oil consisting largely of unsaturated hydrocarbons, together with paraffins, naphthenes and probably smaller quantities of aromatics, together with phenols, consisting of cresols, xylenols and others of unknown constitution, and nitrogenous bases.

The above quoted work would appear to confirm substantially the majority of the facts put forward in this statement, which represents a fair description of low-temperature tars in general.

It will be noticed that the yields of the tars mentioned in the work under review represented in practice 67.7 and 61 per cent, respectively, of that obtainable by the laboratory assay apparatus of Gray and King, and with one exception, where 80 per cent of the theoretical was obtained, commercial yields may be taken to vary between 50 and 70 per cent of the theoretical.

Tar yields by low-temperature carbonization do not appear to be very much higher than in gas manufacture practice and the percentage of phenols in the primary tar may be as much as from 30 to 40 per cent and even higher in some cases. The value of the phenols as such, should low-temperature carbonization ever become a prosperous industry in this country, is a moot point, bearing in mind the quantity which could

(1) *Jour. Inst. Petr. Techn.* 1924, **47**, pp. 854-871.

then be produced; their conversion to valuable hydrocarbons by hydrogenation should be possible, but this introduces a further process of an expensive kind.

Contrary to the generally accepted view hitherto held as to the value of strongly phenolic oils for Diesel engine purposes, Spilker ([1]) states that these are quite suitable for this purpose.

A 500 h.p. Diesel engine was run by him successfully for three months on a coal-tar having 40 per cent of phenolic substances, without any trace of corrosion and without any difficulty of operation. Such oils are stated to suffer from the disadvantage common to other fuel oils, of containing sulphur compounds which are injurious to some metals. Phenolic oils which do not contain objectionable sulphur compounds give satisfaction, the decrease in calorific value, compared with that of a non-phenolic oil, being from 1 to 1½ per cent for a content of 10 per cent of the higher phenols. Phenols, although acidic, are stated not to attack any of the metals which enter into the construction of Diesel engines.

These facts suggest vast possibilities for the utilization of such oils if the necessity should arise, or in the event of their production in bulk becoming established.

The motor fuel fraction of low-temperature tar would make a good substitute for commercial petrol, but high refining losses are to be expected and physical methods would be preferable for this purpose than chemical.

Low-temperature oils do not give fractions suitable for lubricants owing to their strong tendency to oxidize, and a use has yet to be found for the pitch. The latter would need to be treated as a mixture of crude organic substances requiring considerable investigation before it could be utilized, rather than as a substitute for natural asphalt.

Those fractions corresponding to the lubricating oil distillation range might be reduced for lubricants by a process of hydrogenation, but this would introduce a further complicated process and low-temperature carbonization is already sufficiently complicated.

([1]) *Bren Chemie.*, 1926, **7**, 170-173.

The refining of a low-temperature tar such as would be obtained from bituminous coal in this country would not be so simple a problem as the working up of brown coal tar.

For example, primary tar from bituminous coal is liquid at ordinary temperatures, whereas that from brown coal is semi-solid, which is accounted for by the fact that the former is rich in liquid phenols but poor in paraffin wax, whereas the reverse is the case with brown coal tar. The Deutsche Erdöl, A-G., has marketed brown coal tar lubricants for some time, and although they are not equal to similar products from petroleum from the point of view of lubricating qualities, purity, smell and pour point, nevertheless these oils have helped to reduce imports of lubricants in Germany to some extent, and appear to be of considerably more value than similar fractions obtained from bituminous coal tar.

Again in the case of the primary tars obtained from bituminous coals, the separation of the dust, which all tars of this description carry in varying degree, even after passing through dust separators, depending on the method of carbonizing and whether horizontal or vertical retorts are used, is a factor to be considered, especially in view of the amount of care exercised in keeping our stills, particularly of the cylindrical type, free from solid matter of this kind. The separation of the water in suspension, the amount of which varies not only with the conditions mentioned for dust collection, but also very considerably on the type of coal used and the thermal gradient applied throughout the process, is a further problem to be overcome in distillation: and finally the refining of the distillates and the losses to be encountered with our present methods of 'treating' are all points needing investigation before these tars can be used, otherwise than as fuel for external and internal combustion.

A further point of interest which is made clear as a result of the investigations of Sinnatt and his collaborators (*loc. cit.*) is that, in treating filtered tar with various common organic solvents, in no case was complete miscibility of the soluble portion with petroleum fuel oil possible until 35 per cent of the tar had been separated as a precipitate. This quantity was found to be 8 per cent greater than the amount of pitch

obtained by distillation, and this rules out one of the advantages of a separation method: if the yields of miscible oil were identical, it is doubtful whether the cost of a separation process would not be greater than that of distillation. The oils from distillation and solvent separation do not differ greatly, however, and no advantage would appear to accrue from the latter.

The method of low-temperature carbonization which commends itself most to the author is that of carbonizing at the furnace mouth and either using the semi-coke directly from the discharge box to the furnace to raise steam by means of a chain-grate or, better still, to pulverize the semi-coke and blow it into the furnace in a finely-divided form. In either method the uncondensable gases could also be burned in the furnace.

By carbonizing at the furnace mouth, the establishment of optimum conditions for carbonization is not so essential: the increased efficiency in combustion which would be brought about by the use of pulverized semi-coke over that of raw lump coal should more than meet the carbonization losses in solid fuel; the tar obtained could be treated as a by-product of secondary importance.

Such a method could be more easily adopted hurriedly than the building of unwieldy batches of large retorts, all requiring different carbonizing conditions depending on the type of retort and coal used, as the units would of necessity be quite small and could be built locally. The number of central power stations using steam in Great Britain should make this scheme an attractive form of producing a liquid fuel within the country, particularly in times of stress, and increase our general boiler efficiency considerably.

Very little work on a large scale has been done in this country on pulverized fuel, but considerable advance has been made in the United States, Canada, and on the Continent, and it is surprising that more steam is not raised in Great Britain by this means now that so much information is available on the subject.

Although problems still remain to be solved, particularly in regard to the type of plant best suited for our own particular coals, especially those of inferior grades by means of which

much steam is raised in this country, nevertheless the principles are now well established.

The average steam boiler efficiency in Great Britain is said not to exceed 60 per cent, which represents an efficiency loss equivalent to about 20 million tons of coal per annum. Where a mechanically stoked boiler is working under a steady load it is doubtful whether it would pay to convert the existing plant, but where sudden peak loads develop, pulverized fuel is the most efficient.

This superiority in thermal efficiency would appear to increase with rise in the peak load and the suddenness with which it is applied. Interesting and valuable information regarding the advantages of pulverized fuel has been put forward by Chapman([1]) and also Brownlie([2]).

Pulverized fuel firing owes its increased efficiency over all other practical means of solid fuel stoking partly to its ease of control, but mainly to its ability to reach and maintain efficiencies of about 80 per cent, even when working at a load of four times the normal rating of the plant: this is due to the smaller excess of air needed to ensure complete combustion—*e.g.*, 20 per cent instead of, say, 40 per cent with lump coal; the smaller loss of carbon in the ashes, which is under 1 per cent instead of 2 to 5 per cent or even greater, and to the lower flue gas temperatures, which are about 200° F. instead of 400° F. or greater.

By cooling the walls with air, enlarging the combustion chamber, reducing the velocity of the coal feed and the introduction at the bottom of the furnace of a water screen consisting of a series of water-cooled steel tubes, the erosion of the walls of the plant and the fusing of the ash have been eliminated. Further, the air circulating in the hollow brickwork is used to supply the bulk of the air for combustion.

In general, pulverized coal is obtained by crushing the coal and passing it over a magnetic separator to remove iron particles. It is then dried down to 7 per cent of moisture or less and pulverized in ball mills so that about 90 per cent passes 100 mesh and 65 per cent passes 200 mesh. The coal is then conveyed to feeders where it is mixed with 10 per cent

(1) *Fuel*, 1925, **4**, 340, 396, 420, 486.
(2) *Mining Mag.*, 1924, **30**, 114; *Jour. Inst. Elec. Eng.*, 1924, **62**, 385.

of the required air, and delivered to the burners where the remaining air, which is preheated to a high temperature as already described, is added.

The result is said to be a flame of 2,000° F. intensity with no smoke and the flue gases show a carbon dioxide content of from 17 to 18 per cent, with no carbon monoxide present.

There would appear to be nothing in this process which could not be applied to the pulverizing of low temperature coke, with additional advantages as given earlier: the burning of this semi-coke with the uncondensable gases formed during carbonization should present no difficulty in view of the fact that pulverized coal has been found to work well with blast furnace gas and coke oven gas.

Before leaving this subject, a few remarks on colloidal fuel might be of interest. The chief drawback to colloidal fuel in the past has been its instability, but the United States Navy Department and the Submarine Defence Association have recently reported that pulverized coal can now be successfully held in suspension so that the colloidal liquid flows freely through the pipes, preheaters, and burners of ships, and power, heating and industrial plants equipped to burn fuel oil. Even months after mixing, the composites are said to have shown little or no deposits. A fixateur, which comprises about 1 per cent, stabilizes the particles of pulverized coal dispersed in the oil. Such a mixture would contain the ash of the coal and it is not suggested that it would be suitable for any other purpose than that of burning under boilers.

BERGINISATION

The Bergius process has one great advantage over low temperature carbonization in that it converts coal in one stage into a tar, similar in many respects to a primary tar such as has just been described, excepting that the phenol content is very much lower and the aromatic content higher. The treatment employed, which is now well known, consists essentially of the action of hydrogen under pressure of about 150 to 200 atmospheres, on coal at temperatures of about 450°C. to 480°C.

Experiments show that hydrogenation takes place over a limited range of temperatures only, the speed of hydrogenation increasing with rising temperature to a limit which is governed by the velocity of coking: recent information points to the inhibition of coke formation by the addition of water.

There is also a minimum partial pressure of hydrogen below which hydrogenation will not take place, which necessitates the use of a gas containing at least 80 per cent of hydrogen. Up to 4.5 per cent of the hydrogen enters the coal molecule.

The success of this operation in practice would appear to be governed to some extent by the expense of the hydrogen, and Bergius, who has carried out over 2,000 experiments on a laboratory scale, now appears to be meeting with difficulty in obtaining supplies of the gas for his large plant.

Broadly speaking, British bituminous coals will yield, under these conditions, up to 50 to 60 per cent of tar, 15 to 20 per cent of gas and 10 per cent of solid organic matter representing unchanged or partly changed coal, and coals designated as of inferior grade for ordinary purposes are quite suitable for hydrogenation although those with less than 85 per cent of carbon content give the most favourable results. The tars obtained contain as a rule a good deal of pitchy and asphaltic matter.

Earlier experiments were carried out in a bomb of small capacity working on the batch principle, but later work has been carried out on a continuous plant of larger size capable of treating three-quarters of a ton of coal per day.

The following is a description of Bergius's plant([1]):

A paste is first made of the coal to be berginised with a heavy fraction of tar from a previous experiment and passed through a stirring device, constructed to withstand a working pressure of 150 atmospheres, where it is preheated in company with the amount of hydrogen to be used, to about the working temperatures. The material then flows over into the reaction vessel proper, which is similar in construction to the stirrer, and the reaction products leave the apparatus together and are cooled in a worm condenser. After leaving the condenser

([1]) *Zeit. Ver. deut. Ing.*, 1925, **69**, 1313, 1359.

the pressure is reduced to atmospheric pressure through a suitable reducing valve and the products then pass into a receiver where gas and liquid separate.

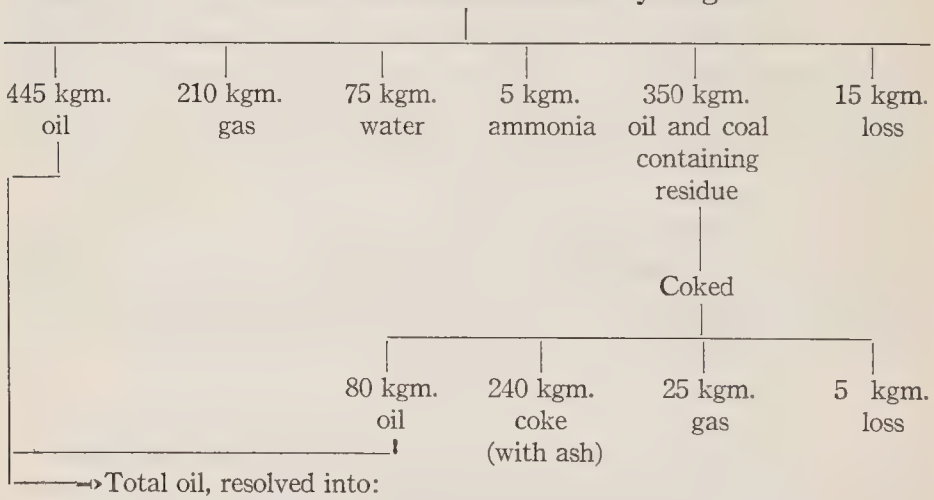
The gas, after the light condensable oils have been extracted, is collected in a gasometer and used when needed, while the solid and liquid portions are drawn off through a valve and separated.

Until recently the nature of the product obtained from coal by this process was a matter of some doubt. Bergius has claimed that from his large scale continuous apparatus the oils yield benzines which are wholly saturated in nature.

An insight into the approximate yield of products by the continuous method is given by Bergius.

Yields from Gas-flame (Bituminous) Coal

One ton (metric) dried gas-flame coal (6 per cent ash) mixed with iron oxide and treated with hydrogen.



150 kgm. refined motor spirit (boiling range 30-230°C.)
200 " Diesel oil
60 " lubricating oil
80 " fuel oil
35 " distillation and refining loss.

It will be noticed that the products total 1,100 kgm., whereas the original material weighed 1,000 kgm. This increase in weight might be made up by the amount of iron oxide usually employed by Bergius and the hydrogen absorption.

The distillation and refining losses represent nearly 7 per cent of the tar formed, but as they are not expressed separately, and the method of refining and which fractions were refined is not mentioned, little information is available for the purpose of this paper.

A sample of Bergius tar was examined in our laboratory as follows:

Moisture content, 4.86 per cent. Ash content, 12.38 per cent. The oil was extracted with ether in a Soxhlet apparatus and the ether extract washed with sodium carbonate, caustic soda solution, and dilute sulphuric acid respectively to remove acids, phenols and bases. On removal of the phenols and bases further amounts of ether insoluble solid were precipitated, and these were termed phenol-soluble solid and base soluble solid.

Constituents of the oil in percentage by weight:

Ether insoluble solid (ash=27.73 per cent)	38.51
Base-soluble solid	3.23
Phenol-soluble solid	0.49
Phenols	3.74
Bases	3.86
Acids	traces
Neutral oils	38.10
Water, ammonia and loss	12.07
	100.00

Distillation of neutral oil:

Percentage by weight.	
Up to 175°C.	1.83
175°—225°C.	7.06
225°—300°C.	30.68
above 300°C.	58.99
loss	1.44
	100.00

The tar was extremely viscous, difficulty being experienced in pouring even at room temperatures: it contained much solid both in suspension and solution, and would appear not to have received such prolonged treatment as would be the case with the Bergius tar previously referred to.

In this reaction it is interesting to note that although Bergius considers catalysts are not necessary, 5 per cent of iron oxide is always added to the autoclave charge. Recent

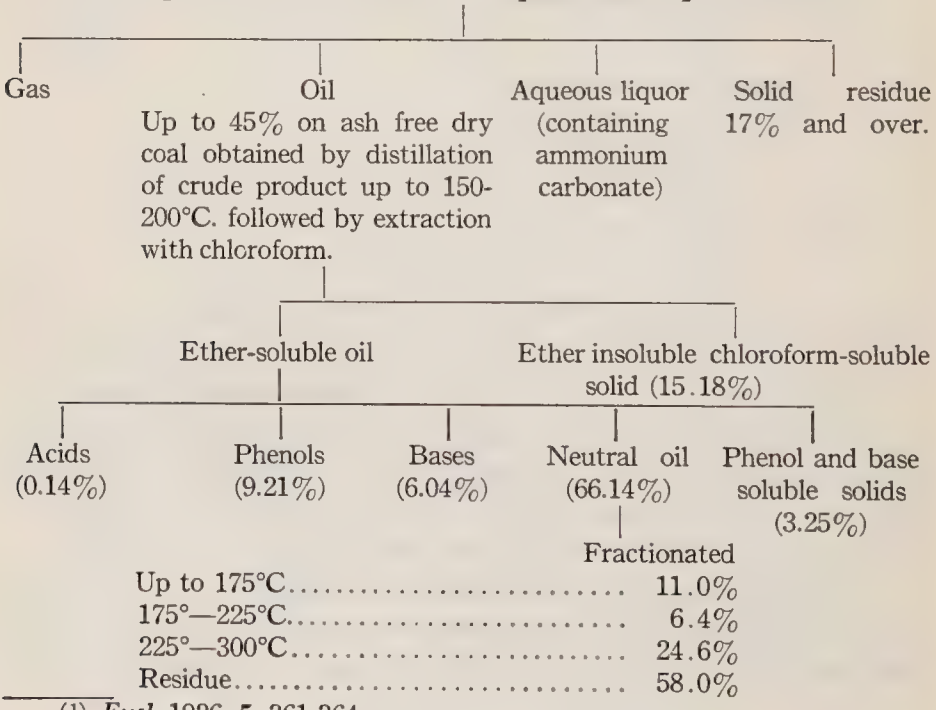
researches by Bowen([1]) in our laboratory have shown that catalysts have a pronounced effect in causing hydrogenation instead of coke formation: nickel oxide having a greater influence in this direction than iron oxide. The nature of the oil obtained was also studied and phenols and bases were shown to be present to the extent of 9.21 per cent and 6.04 per cent respectively, in the case of the coal investigated.

The light oils had an iodine value of the order of 150 (Wijs) and a loss to sulphuric acid of approximately 50 per cent. It should be mentioned, however, that our results may not be exactly comparable with those of Bergius, as no diluent was used; also, owing to the discontinuous nature of our plant, it is possible that some of the compound formed may have undergone slight secondary change. The liquid we obtained, whilst it contained a nucleus of neutral oils, could not be said to resemble a natural petroleum oil: it appeared to bear a closer similitude to a low-temperature tar excepting that its phenolic content was lower.

The diagram below shows the nature of the liquids obtained.

Experiments with Arley Coal.

Arley coal, mixed with metallic oxide—*e.g.*, Fe_2O_3 or NiO and stirrers was treated in an autoclave with hydrogen at pressures up to 180 atm. and at temperatures up to 480°C.



([1]) *Fuel*, 1926, **5**, 361-364.

Ormandy([1]) in his examination of a spirit, as received from Germany, which was obtained from a tar produced from an English coal in the continuous plant of Bergius, showed the composition to be—unsaturateds 3.1 per cent, aromatics 7.5, paraffins 47.0, naphthenes 27.0, and residue 15.4 per cent. The aromatic content in this case would appear to be lower than would be expected.

A detailed analysis of the tar and oils obtained from unwashed coal-dust containing 17.7 per cent of ash, 28.5 per cent of volatile matter (on dry coal) and an exceptionally high proportion of fusian (which is known to yield very little oil on 'berginisation') has been made by Heyn and Dunkel([1]). The coal was made into a paste with half its weight of an oil obtained from a previous 'berginisation' of similar coal, and the experiment was run continuously for 2½ days at a throughput of 7 kg. of paste per hour.

Total yield was 36.45 per cent of the raw coal—*i.e.* 33.09 per cent of oily product and 3.36 per cent of spirit recoverable from the gas. The black viscous tar contained 29.5 per cent of dust, to remove which the light oils were distilled off up to 230°C. (during which ammonium carbonate separated out in the receiver) and the residue was dissolved in benzene and filtered warm.

After removing the benzene, the light and heavy oils were united and fractionally distilled (above 220°C. under reduced pressure) up to pitch which was 9.26 per cent of the raw coal. The oil fractions were extracted by the methods for phenols, bases, etc., showing the total distillate to be composed of 75.7 per cent of neutral oils, phenols 12.0 and bases 3.5 per cent, and small traces of carboxylic acids, resin, and sediment. The solid constituents of the neutral oils comprised a small quantity of paraffins and a considerable quantity of aromatic hydrocarbons.

Difficulty was experienced in removing the oil completely from the dust, which, after extraction, contained 40.65 per cent of ash and 10.45 per cent of volatile matter.

Of the phenolic compounds 10.3 per cent was phenol itself, whilst phenol, cresols, and xylenols (b.pt. up to 220°) consti-

([1]) *Journ. Inst. Petr. Techn.*, 1926, **12**, 77-78.
([1]) *Brenn. Chem.*, 1926, **7**, 20-25; 81-87; 245–250.

tuted 66.5 per cent of the whole. The basic fraction contained primary, secondary and tertiary bases: the 'benzine' from the gas was refined with sulphuric acid and fractionally distilled, the bulk distilling below 185° and contained benzene, toluene and xylene with a large proportion of their hexahydro-derivatives.

The light oil fraction (b.pt. up to 180°) of the main product refined and fractionally distilled, had an analogous composition, the ratio of aromatics to hydro-aromatics being, however, greater than in the 'benzine.' The higher fraction (180-220°) of the oil contained naphthalene and its tetrahydro- and decahydro-derivatives. All the neutral oil fractions were remarkable for their low sulphur content (0.76-1.12 per cent).

The Bergius process is a distinct advance over low-temperature carbonization from the point of view of liquid fuel formation, as not only is a larger production obtained but there is no large amount of disposable residue left behind.

The difficulties to be encountered in working up this 'berginised' tar would appear to be similar to those encountered in the refining of low-temperature tar to some extent in that the separation of the solid matter (about 30 per cent of the crude tar) would be a problem of some magnitude in large scale practice.

The spirit fraction would make an excellent substitute for motor fuel—indeed it should be superior to many petrols at present on the market—and the pitches formed certainly bear a closer relationship to true pitch than the low-temperature variety, although the ash content is high. Attempts to prepare a satisfactory lubricating oil from the higher fractions without further treatment do not appear to have been very successful (reference has already been made to the fact that distillation range does not, of necessity, point to the presence of good lubricating fractions), but Spilker([1]) has shown that these higher boiling fractions can be reduced by further treatment in the Bergius autoclave whereby a new class of artificial lubricating oils might be obtained, the viscosity of the resulting oils rising with the molecular weight of the parent compounds.

([1]) *Z. angew Chem.*, 1926, **39**, 997-9.

SYNTHETIC FUELS FROM CARBON MONOXIDE AND HYDROGEN

As already mentioned, coal can be carbonized at high or low temperatures resulting in yields of coke, tar and gas differing considerably from each other in constitution. The residual coke from both these processes can be followed by complete conversion into gaseous and oil products, water gas being the medium whereby this can be done. This gas can be obtained by passing steam through incandescent carbon.

At temperatures of 1,000°C. carbon monoxide and hydrogen are the chief products:

$$C+H_2O \rightarrow CO+H_2.$$

The temperature must be maintained at 1,000°C., or below this carbon dioxide is formed thus:

$$C+2H_2O \rightarrow CO_2+2H_2.$$

The impure mixture of hydrogen and carbon monoxide is technically known as 'blue water gas,' to distinguish it from the mixture of water gas and oil gas, a substitute for coal gas, sometimes referred to as 'carburetted gas.'

A typical analysis of blue water gas is as follows:

Hydrogen	52.0 per cent.
Carbon monoxide	38.5 "
Carbon dioxide	4.5 "
Methane	1.0 "
Nitrogen	4.0 "

Two methods, both catalytic, are open for the production of synthetic fuels from these gases, the first a high-pressure process giving methyl alcohol, higher alcohols, etc., and the second a low-pressure method giving gaseous, liquid and solid hydrocarbons; the latter process has been investigated in our laboratories on both a small and semi-commercial scale.

The first work to be considered will be that of Sabatier, who in 1905 pointed out that as two of the valency directions of carbon monoxide are unsatisfied, the molecule will combine with oxygen, sulphur and chlorine, and it should combine therefore with hydrogen to give formaldehyde and then methyl alcohol. Hydrogen and carbon monoxide were passed over finely-divided nickel, which was heated in a glass tube, but the products were found to be methane, water and carbon dioxide. It should be mentioned in passing that this process

has been developed on a technological scale and is now known as the 'Cedford Gas Process' for the conversion of the carbon monoxide of water gas into methane.

Up to the year 1913 the formation of methane, carbon dioxide and water was the only established reaction when carbon monoxide and hydrogen were led over a catalyst.

The next advance in the conversion of water gas was made by the well-known German firm, the Badische Anilin und Soda Fabrik, who succeeded in converting this gas mixture into liquid products, consisting of hydrocarbons, alcohols, ketones, aldehydes, organic acids and water. The technique followed was that of passing the water gas, at a pressure of about 100 atmospheres, over a catalyst heated to from 300° to 400°C.

This process was patented (E.P. 20,488) in 1913 and appears to have been the first successful synthesis of a possible liquid fuel from water gas, but it does not seem to have been carried out on a commercial scale.

Since that date investigations of a similar character have been carried out in Germany, France, America and this country.

According to theory, the substance which would be most easily obtained from carbon monoxide and hydrogen would appear to be formaldehyde, as the folllowing equation indicates:

$$H_2+CO=HCHO.$$

Such is not the case, however, and it has been found that methyl alcohol is most probably the primary product, so:

$$2H_2+CO=CH_3OH.$$

This alcohol, which boils at 66°C. is readily formed in a pure state when a suitable catalyst is employed. The B.A.S.F. in Germany, and Patart and Audibert in France, have developed this process in the last seven years, and it has been stated that the B.A.S.F. production of methyl alcohol has run into the order of thousands of gallons per diem.

Generally the catalysts used for the production of pure methyl alcohol are free from alkali and iron. If the catalyst contains such substances as, say, potassium carbonate and reduced iron, then other substances besides methyl alcohol appear in the product: these may be hydrocarbons or may contain oxygen.

The formation of oxygenated compounds by catalysis under pressure has been studied in Germany by the B.A.S.F. and by Fischer. The latter investigated the former's patent of 1913, and developed an iron-alkali catalyst with the object of synthesising a mixture of compounds suitable for use as a fuel in internal-combustion engines. With this catalyst he obtained an aqueous and oily liquid, some 87 per cent of the latter distilling below 200°C. The work of this investigator(1) constitutes an interesting series of experiments on the reduction of carbon monoxide and hydrogen, the initial pressures in the successful experiments being 100 atmospheres or over, but dropping off as the reaction proceeded, causing a gradual diminution in the quantity of alcohol and oil formed; the temperature of the contact tube was kept constant at 410°C.

The following table by Mittasch summarises the substances which have been isolated from the reaction products when compressed carbon monoxide and hydrogen are passed over various catalysts at temperatures of about 200 to 450°C.:

PRODUCTS FROM CARBON MONOXIDE AND HYDROGEN (HIGH-PRESSURE CATALYSIS)

Carbon monoxide and hydrogen

(Formaldehyde) CH_2O ?

(Methyl alcohol) CH_3OH

Derived products

I. Alcohols	II. Ether and Esters
(Ethyl alcohol)	Dimethyl ether
n-propyl alcohol	Methyl formate, etc.
Isobutyl alcohol	
Iso amyl alcohol B.pt. 128°	III. Aldehydes and Ketones
Hexyl alcohol (148°)	Isobutyl aldehyde
Heptyl alcohol (160°—165°)	Acetone
Octyl alcohol (180°)	Methyl ethyl ketone, etc.
Higher boiling alcohols.	

(1) "Conversion of Coal into Oils," *Brenn. Chem.*, 1923, **4**, 276; 1924, **5**, 210.

With the higher alcohols the type $R—CH.CH_2OH$ appears to preponderate
R_1

IV. Free or combined acids
(Formic) acid
(Acetic) acid
(Propionic) acid
Isobutyric acid
Valeric acid
Caproic acid

V. Hydrocarbons.
Liquid hydrocarbons of most diverse kind. B.pt. 20° to over 300°.

Gaseous hydrocarbons especially methane.

VI. Cyclic compounds.

It should be pointed out that so far methane and methyl alcohol are the only substances which can be obtained, directly, in a state of purity, from the catalytic process. Modification of the catalyst used for methyl alcohol production has up to the present led only to the production of mixtures of the substances shown in the previous table.

Before passing on to the catalytic processes which are applicable at ordinary pressure, consideration of the possibilities of using these synthetic substances as fuels in internal-combustion engines should be given.

Methyl alcohol is not regarded with favour as a petrol substitute, one reason for this being its tendency to pre-ignition. This can be eradicated to a great extent by the addition of some 5 per cent of water, which acts in this case as an 'anti-knock' substance, when half the mileage per gallon given by petrol is obtainable.

The mixture of ketones and alcohols, etc., would seem more favourable for use in internal-combustion engines, but the organic acids would have to be removed from the mixture.

The hydrocarbons are of most interest to this Institution of course, but a study of the other compounds is essential in order that the cause of their formation may be investigated with a view to their possible interdiction if necessary.

Fischer states that he has tested his synthetic mixture in a 4-h.p. motor cycle, and found it to be a satisfactory fuel.

Until a short time back, it was thought necessary for the reaction to be carried out under high pressures in order to produce these synthetic fuels, but an unexpected development in the inter-action of carbon monoxide and hydrogen has opened up new ground in the field of synthetic fuel: a process

has been investigated which is carried out at atmospheric pressure whereby these gases are converted into hydrocarbons similar to petroleum.

This process was described by Fischer(1) at Mulheim, and depends on the use of catalysts prepared from mixtures of reduced oxides containing iron and cobalt. Passed over such catalysts a mixture of carbon monoxide and hydrogen is converted, at temperatures in the neighbourhood of 270°C., into water, carbon dioxide, gaseous, liquid and even solid hydrocarbons, the latter resembling vaseline in appearance. Fischer states that no oxygen compounds were formed and the various hydrocarbons produced, as is to be expected, were free from sulphur; so that if the process were carried out on a commercial scale it would be necessary only to separate the water formed and fractionate the hydrocarbons.

It is of extreme interest to observe that the catalyst can be so modified that the proportion of high boiling constituents can be increased. There is thus a possibility of synthetic lubricants as well as synthetic fuels from this process.

As the contact mass is obviously of prime importance in this reaction, it will be considered in some detail. The catalysts employed were the metals, or partly reduced metals, of group 8 of the periodic classification, and it was considered expedient to make additions to prevent sintering and to accelerate carbide formation (high-carbon-content carbides being considered by Fischer and Tropsch to be the intermediate compounds formed in this reaction).

The passage of hydrogen and carbon monoxide over iron and zinc oxide gave a mixture of methane and homologues, but more active catalysts were discovered: the use of cobalt and chromium oxides at 270°C. led to the formation of liquid and solid, as well as gaseous, hydrocarbons; numerous passages of water gas over the reduced oxides of iron and cobalt gave 100 gm. of liquid and solid hydrocarbons.

A contact mixture, consisting of the reduced oxides of iron and copper, proved many times more active than reduced iron alone dispersed on an asbestos carrier. The addition of small amounts of potassium carbonate to oxide mixtures of this composition led to the formation of high boiling oils and solid paraffins; the addition of sodium carbonate led to a petro-

(1) *Brenn. Chem.*, (1926), **7**, 197; *Ber.*, (1926), **59**, 830-832.

leum-like oil, whilst barium hydroxide led to products intermediate in volatility. Detailed information concerning the various experiments carried out is not available.

In combination with the 'iron' metals were used chromium, zinc, beryllium, rare earth metal, uranium, silicon, aluminium, magnesium and manganese oxides, active charcoal, and amorphous carbon, the order given being that of decreasing efficiency.

The contact mixtures employed were prepared by the usual methods—viz., by precipitation or by heat decomposition of suitable salts, followed by reduction with hydrogen at 350°C. usually.

Purified water gas was used in the later experiments of Fischer and Tropsch, and the products obtained ranged from gaseous to solid hydrocarbons. Water and carbon dioxide were formed by the elimination of oxygen from carbon monoxide. Ethane, propane and butane were identified, with only small amounts of ethylene, propylene and butylene, as gaseous products of reaction. From the liquid products were obtained fractions corresponding with benzine and a heavier petroleum.

It is of much interest to note that analyses of the liquid fraction showed the absence of oxygenated compounds. The formation of hydrocarbons only, in this process, is explained by Fischer on the hypothesis that carbon is removed from the carbon monoxide by the contact mass to form high-carbon carbides, which are then decomposed by hydrogen to give 'methylene'. This hypothetical body can then, according to the conditions, polymerise and be further hydrogenated, or else be hydrogenated directly to methane. The catalyst must therefore have the power of carbide formation.

The formation of hydrocarbons has been confirmed in our laboratories by Elvins(1), who has obtained from carbon monoxide and hydrogen, by the use of a contact mass of reduced copper, cobalt and manganese oxides, not only hydrocarbons, but has increased the scope of this reaction considerably by proving the presence of oxygenated substances soluble in water (2).

Artificial water gas was passed over the reduced oxides of cobalt, copper and manganese at about 280°C., which resulted in the partial conversion of carbon monoxide and hydrogen into solid, liquid and gaseous organic substances.

(1) *Fuel*, 1926, **5**, 263.
(2) *Nature* (1926), **118**, 154.

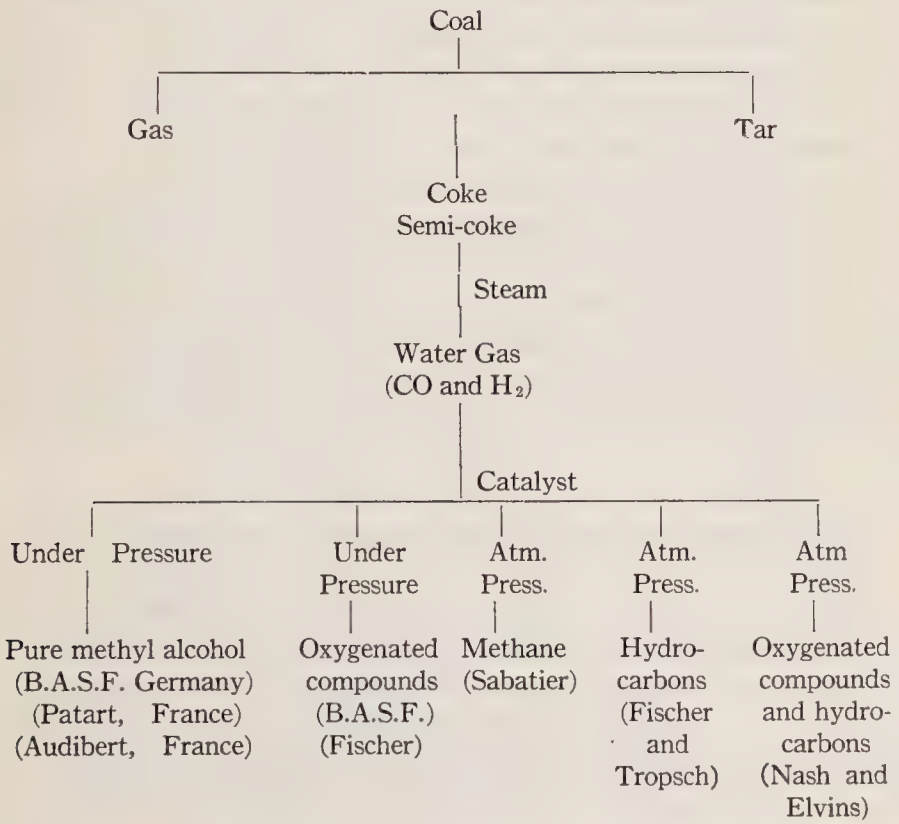
The latter were carried over by the gas stream through tubes containing activated charcoal, which retained all the solid and liquid substances which had not already condensed out at ordinary room temperatures.

These were recovered from the charcoal by steam distillation, and it was found that the distillate separated into two layers, an aqueous and oily layer. Distillation of the aqueous layer showed the presence of small quantities of organic bodies boiling below 100°C. The latter consisted partly of organic acids, whilst the oily layer contained hydrocarbons.

It thus seems possible that the product approximates to the mixture obtained at high pressures, which has been already discussed and which would be suitable for use as fuel.

Since this work has been published, Fischer and Tropsch have confirmed the formation of oxygenated bodies under similar conditions to those investigated in our laboratories.

The following diagram sets out briefly the work carried out by various investigators and the nature of the products obtained:



With regard to the application of these processes on a works' scale, the 'Cedford Gas Process' already mentioned is an instance where water gas can be converted by catalytic treatment into the gaseous hydrocarbon methane, so it is evident these low-pressure methods may also be carried out on a technical scale.

The reduction of carbon monoxide and hydrogen would at first appear therefore to be a distinct advance in the direction of independence of foreign liquid fuel supplies to those countries devoid of natural petroleum, but on further consideration many disadvantages occur to the mind—*e.g.*, the formation of these liquid products seems much slower than that of methane, and the catalyst used is slowly fouled by the presence of high-boiling substances. This would necessitate continual steaming out, in a current of air, followed by reduction.

The isolation of the products would require a process similar to that whereby light spirit is recovered from coal and natural gas: adsorption by activated charcoal, followed by steaming would appear to be a suitable method. The careful purification of the reactants, which would involve an increase in capital and running costs, of course, would render the products amenable to simple refining, as, unlike berginisation oils, they would be free from sulphur.

The escaping gas, containing the lower members of the paraffin series, could augment the ordinary gas supply, possibly obviating the necessity for carburetting water gas, and in the author's opinion, if and when the necessity arises for such methods to be tried out, the existing gas undertakings would appear to be the most suitable places for the complete process from the carbonizing of the coal up to the reduction of water gas.

DISCUSSION OF THE PROCESSES DESCRIBED

So much has been written on the value of power alcohol as a motor fuel that only a brief discussion will be entered into in this paper. It is sufficient to say that it is the only source of motor fuel at present in sight, excluding that which could be obtained from shales, torbanites, etc., which could appreciably respond to a petrol shortage.

Should this fuel ever be used on a large scale, alterations in the existing design of engines would be necessary, for the reasons already stated. Petrol and alcohol containing small amounts of water do not mix in all proportions, but if benzol is added they are completely miscible. The main disadvantage is entirely one of cost, for all the methods given under this heading.

In regard to oil shales, etc., the time for their exploitation has not yet arrived, but should the demand for petroleum ever exceed the available supply, prices would, of necessity, rise and this would represent the period when the value of oil shale and similar bituminous material as a source of petroleum would become established. The similarity of shale oil to petroleum, not only in its physical and chemical characteristics, but also in its amenability to known methods of treatment such as are used in our existing refineries, renders its utilization the next stage in the development of a substitute for free petroleum, a certainty.

How soon this will occur no one can predict: it must be borne in mind that no systematic geological investigation of the structure of the earth's crust has yet been made excepting in a few strictly limited areas, and before an opinion can be accepted as of any material value regarding the future supplies of free petroleum, we must first satisfy ourselves that all possible geological structures favourable for the accumulation and retention of oil have been examined. In all the oil-producing territories of the present time, with the exception of a few oilfields in America found as a result of 'wild catting,' the knowledge that oil was present was not due to any original discovery on the part of the petroleum technologist: in practically all cases our existing oilfields have been located as a result of surface indications of oil, but the application of physical science to geological investigation in the future will undoubtedly bring to light a number of oilfields the existence of which is at present unknown.

The Alberta tar sands, at the present time, hardly come into a general survey of the subject under discussion, although possibly of extreme future importance to Canada.

The greatest opposition which low-temperature carbonization of coal is likely to encounter, should it ever develop to

the commercial stage, would be as a result of the economic law of supply and demand. At present all the financial balance-sheets put forward in support of this process have shown the semi-coke priced at least as high, and in many cases higher, than the original coal, weight for weight. Should this smokeless fuel ever seriously compete with household coal, the time might arrive when the collieries would be forced to lower the price of household coal in order to dispose of it, and obtain their profit from the coal sold for carbonizing purposes. Again, the necessity of disposing of both the semi-coke and the tar in the proportion of, say, 14 cwt. of the one to 14 to 20 gallons of the other, is a problem which is not so simple to solve as it appears on paper.

For the reasons given earlier, low-temperature tar can never replace petroleum in normal times, and the cost of working it up into any product other than fuel for internal and external combustion would be excessive at the present time.

The Bergius process would appear to have a more doubtful future in this country in normal times, from the point of view of liquid fuel production, than low-temperature carbonization.

The chief difficulty in the way of its successful exploitation on commercial lines, with crude petroleum at or about its present price, would appear to be capital, maintenance and running costs. The construction of a plant for large quantities offers extraordinary difficulties, as apart from those of a purely constructive nature, such as obtaining pressure-tight seals, safe working joints and valves, and the very extensive apparatus for the testing of the plant, care must be taken to permit of an accurate temperature control.

For such a purpose Bergius has found that the heating of the apparatus externally is unsatisfactory and the method of heat transference necessary is through the medium of an inert gas passing through an annular space surrounding the reaction chamber proper. The effect of heat on the structure of the metal is another point to be considered, as all steels lose a certain proportion of their strength after being subjected to prolonged heating above 400°C.—*e.g.*, some steels tested in our Civil Engineering laboratory were found to break down, after being kept at a temperature of 450°C. for several weeks, with a tensile stress of from half- to one-quarter of that

which they could withstand normally. This means that special steels which have undergone prolonged metallurgical heat treatment would be necessary, and even then a high factor of safety would be desirable, particularly as erosion of the autoclave walls is bound to take place in time, in view of the sulphur content of the coal, all of which adds to the weight and cost.

The question of a sufficient and cheap hydrogen supply is one to be considered: also the manipulation of a plant of this kind would appear to be beyond the skill of the average artisan and wages and salaries are likely to be high.

In regard to the reduction of carbon monoxide and hydrogen, it has been shown that pure methyl alcohol can be obtained by the high pressure process whereas with the low pressure technique pure hydrocarbons, ranging from the low boiling fractions up to solid waxes the proportion of each of which can be varied according to the catalyst used, or a mixture of hydrocarbons and oxygenated compounds, are produced.

Dealing with the high pressure process first, methyl alcohol and its direct derivative formaldehyde would be of particular interest to the pure chemical industry of this country, and the latter is also of importance in the manufacture of synthetic resins of the bakelite class: the higher alcohols which could be produced would no doubt find a market in the paint and varnish trade, or they could even be dehydrated by a further catalytic process to hydrocarbons. From the fuel point of view, however, which is the main concern of this Institution, it is very unlikely that these products will ever enter into commercial competition with petroleum in normal times, despite the statement that methyl alcohol can be produced by this process commercially at tenpence a gallon.

Turning now to the low pressure system, it is extremely difficult to make economic deductions from laboratory scale experiments: it is true that the high pressure plant is very expensive, but on the other hand the plant required for working at the low pressures would have to be very large, and would probably prove just as costly as the high pressure plant—*e.g.*, large contact chambers, or—which would, no doubt, be preferable —numerous small ones, will be required to give good yields of liquid products.

Further, accepting the brief definition of a catalyst as being a substance capable of accelerating a chemical reaction without itself undergoing permanent chemical change, it should be possible for a small quantity of a catalyst to convert an infinite quantity of material. In practice other factors intervene, however, and in the majority of cases the catalyst is eventually incapacitated either by catalyst poisons or by fouling of its surface, the poisons being substances which destroy the action of the catalyst even when present in only minute quantities. Fouling of the catalytic surface is brought about by substances which cover the active surface, these often being the product of the chemical change itself, and it is of interest to note in this connection that Fischer, in some of his experiments, actually obtained his vaseline-like product, in the atmospheric pressure work, by extraction from the catalyst.

One advantage which the production of pure heavier hydrocarbons by this method would appear to have over all the others mentioned is the possibility of obtaining lubricants, and a point which is often overlooked in our desire to ensure an adequate supply of liquid fuel in times of stress is that lubricants and not liquid fuels are the real measure of the development of power.

A serious drawback to the low pressure process from an economic point of view is that, so far as can be seen at present, the oxygen of the carbon monoxide must be largely eliminated either as carbon dioxide or water.

Earlier in this paper the suggestion was made that coal might be subjected to low-temperature carbonization first, followed by the conversion of semi-coke to water gas, afterwards to be reduced to liquid fuels.

Taking into consideration the losses to be encountered in the carbonizing and gasification process, and even greater loss in the reduction of water gas, it would seem that, despite many enthusiasts, we are not yet in a position to dispense with natural petroleum.

In conclusion it should be mentioned that there are two financial balance sheets which can be prepared when considering the value, as auxiliary sources of liquid fuels, of the products described in this paper. With crude petroleum at its present price none of the methods given, with the possible exception of the destructive distillation of oil shale (provided it is rich enough), torbanite, etc., would appear to be a paying proposition, but with crude oil selling at a greatly enhanced figure, as it did in this country during the War, all the processes dealt with might not only pay handsomely, but should provide an adequate and valuable supply of liquid fuel.

INTRODUCTORY REMARKS AND DISCUSSION

PROFESSOR A. W. NASH (England): Mr. Chairman and gentlemen, there are one or two statements I ought to make. This paper was prepared, as one of four, as the contribution of the Institution of Petroleum Technologists in London to this Congress, and it should have been read in Jasper with the other papers: as I am not going there, however, it was put on the agenda for this meeting and I am presenting it here.

In the paper you will read statements referring to "this country". That means Great Britain, and not Canada. Many of the remarks which are made in the conclusion of this paper may not apply to Canada, although they apply to Great Britain.

The work which is described very briefly here is the result of five years intensive research in the Department of Oil Engineering and Refining of the University of Birmingham, that is, since it has been under my charge.

In regard to the tar sands of Alberta, the views expressed in this paper were written before I had actually visited the McMurray tar sands, but I have since paid a visit of two or three weeks duration to that area, and there is no statement which I wish to delete or amend as a result of that inspection.

I should like to add, however, that I think, so far as the production of oil from the McMurray tar sands is concerned, this problem runs more or less parallel with the development of oil shales. I feel that so long as free petroleum is as abundant as it is today, and at or about its present price, working of the tar sands of northern Alberta for the production of oil will not be an economic problem or a commercial success. I think, however, that if and when the demand for free petroleum exceeds the available supply, the McMurray tar sands can then be utilized for this purpose.

In this connection I would like to express publicly my grateful thanks for the very valuable help that I have received from Dr. K. A. Clark, of the University of Alberta, and Mr. S. C. Ells, whom many of you know, of the Department of Mines, in my studies of these deposits.

As a paving proposition, the Alberta tar sands, I am quite convinced, are in every way suitable, provided they are handled rightly, and the pavement laid last year at Jasper by Mr. Ells, and which is being extended by him this year, is a proof of this.

As a matter of passing interest, I would just like to point out, if you will look at the figures referring to the treatment of this bitumen, that by direct distillation a higher percentage of oil is obtained than by either hydrogenation or cracking. If you turn to the yields by fractionation, you will find, however, that the percentage of petrol or gasoline in the direct distillation is only 7 per cent as compared with 38.8 per cent in cracking and 42.5 per cent in hydrogenation. That petrol, as a matter of fact, does not exist in a natural state in the bitumen, but this bitumen is so very unstable when subjected to distillation that cracking cannot be stopped. That is why you get this fraction of petrol. It also brings out very clearly the fact that for the production of cracked petrol, hydrogenation or Berginization shows very little improvement on ordinary cracking. If you will notice the figures, the increase in the yield of gasoline is only about 3 per cent in the case of hydrogenation. If you will also look at the further figures you will see that in direct distillation the loss to sulphuric acid in the petrol fraction is fairly high. In cracking and hydrogenation they are very much lower

and about equal, which would point to the possible fact that the more complex ring compounds have been broken down into simpler hydrocarbons, also of ring structure. This is confirmed to some extent by the fact that the losses to 98 per cent H_2SO_4 are fairly heavy, whilst the losses to 80 per cent H_2SO_4 are negligible. When read in conjunction with the bromine values, this suggests the presence of a fairly high proportion of aromatic hydrocarbons in both the cracked spirit and the cracked distillate as a whole.

At the same time, too much reliance cannot be placed on this interpretation of the loss to H_2SO_4, as a satisfactory method of determining volumes of unsaturated hydrocarbons present has yet to be evolved.

I think the best thing I can do is to turn to the conclusions, because the rest can be read at leisure.

Power alcohol I do not propose to deal with in any detail now. I would like to point out that, so far as the distillation of bituminous coal is concerned, with or without hydrogenation, having heard so much lately about the production of oil from coal and the liquefaction of coal, etc., the oil which is obtained from coal by the Bergius process is really a tar; it is not a petroleum oil as we, that is to say petroleum technologists, understand the term. The spirit fraction from the low-temperature tar, and liquefied coal by Berginization, is quite suitable as a motor fuel; in fact it is superior in some respects to certain natural gasolines. The other fractions are not of such great value; for instance, lubricants are missing and they have other drawbacks, all mentioned in the paper. In regard to their importance to us as an auxiliary supply of fuel, I feel that this importance is only in proportion to their economic value: at present they are of little help. The high-pressure and low-pressure reduction of carbon monoxide and hydrogen is still in its infancy and it is rather difficult to make any prophecy as to the future. From the commercial point of view, the losses at present which occur in the carbonizing of the coal, the gasification of the coke, and the reduction of the carbon monoxide, are so high as to preclude, in my opinion, the possibility of their being used as a rival to

petroleum, excepting under abnormal conditions such as we had during the war, when, I believe, fuel oil in Great Britain rose to somewhere about seventeen pounds per ton.

THE CHAIRMAN (THE HON. PHILIPPE PARADIS): The paper is now before you for discussion, gentlemen.

Mr. V. REICHWALD (England): I would like to take this opportunity, as a member of the British Iron & Steel Institute (I am the only one present, I believe) to thank Professor Nash very much for the work he has done in this paper so far as it affects the interests of the iron and steel industry. I myself am not an oil man, and know very little about oil, but some of the problems that he touches in his conclusions to this paper very nearly touch us, the iron and steel men. Though, in the ordinary way, we do not use liquid fuels, we have a very, very keen interest in the question of obtaining liquid fuels, that is to say, obtaining them from coal, be it black coal, which we call stone coal, or lignite (brown coal) which has the highest percentage of recoverable liquid oils. That subject has been, of course, very much moving both steel masters, and, hand-in-hand with them, colliery owners, because the two go together in the complex conditions of today. A steel concern without a colliery has only one leg to stand on, and a colliery without an outlet for its coal in a definite daily consumption in large quantities is also like a man with one leg, or a man with one eye.

I have had the very great privilege during the last few years of seeing a number of quite modern processes being exploited in connection with colliery and steel-works plants to obtain from a coal that has the smallest market value its biggest return; a coal, let us say, which was valued at the pit-head at about five or six shillings. I am speaking of the continent of Europe particularly. Research was being carried on to find a means of converting this inferior coal into a fuel which would provide the power for mechanical work to be done at the colliery, and to dispose of the surplus power either in the shape of gas or electric energy for use in industrial plants in the neighbourhood.

By separating the small coal from the medium and large coal at the pit-head, a higher market value was obtainable, and resulted in turning the scales in favour of profit where previously there had been a loss: the small coal being the object of further experiments.

They set to work to find a use for this small coal. The nature of the seams was dry, and the amount of moisture in the coal was usually under two per cent. The first plant installed was an air separating plant, through which all the smaller grades of coal were passed and the dusty particles below 120-mesh to the square-inch were sucked off through air suction by a fan system. They were recovering from the bulk of the small coal, i.e., coal through one and three-quarter inch square mesh, twenty-four per cent of fine dust which passed 120-mesh and could therefore be used as powdered fuel, for powdered fuel fired boilers.

This recovery led them to convert the sixteen boilers in their main boiler house from coal-firing to powdered-fuel-firing. This boiler house has 8 pairs of boilers, that is, eight Cornish boilers on one side and eight water-tube boilers on the other side. What struck me then was that these eight water-tube boilers were two and two of four different makes. There were two Babcock boilers, two Dürr boilers, two Steinmullers, and two others, of another make.

These boilers had all been used for chain-grate stoking and had given very widely differing results. The problem that these people were up against was the finding of a suitable arrangement for the combustion chambers. It has always been alleged against powdered fuel in general, that, by introducing the powdered fuel in a stream of air or by means of air injection, you have a tremendous impingement upon the walls of your combustion chamber, and, as the result of that, you are obliged to provide large combustion chambers, otherwise you are going to burn the lining.

The most remarkable thing to me was to see the small dimensions of those combustion chambers in connection with all those boilers, not only the Cornish boilers, where the combustion chamber was built in front of the actual fire flue, but also all four types of water-tube boilers. The reason for that was that they don't blow the powdered fuel in: they

drop it in. They drop it in through the top dome of the combustion chamber, so that it falls naturally in an automatic feed which is adjustable by a hand screw. They blow in primary air and secondary air through the front of the combustion chamber and introduce secondary air at various levels at other points of the combustion chamber simultaneously. So instead of getting a flame which is impinging a matter of four or five yards against the opposite brick wall and against the fire-bricks at the back of the chamber, they obtain a vortex-like flame which plays around all sides of the combustion chamber.

The amount of money saved at that group of collieries since the introduction of powdered fuel firing for their own power-plant amounted in sterling (they showed me their own books) to £56,000 in the first year. The conversion of the sixteen boilers cost a sum less, considerably, than the saving effected in the first year.

I may say Great Britain is very much interested in that system of firing at the present time, and three of our biggest colliery groups in South Wales, in the Midlands, and in the North of England, are at the present time investigating this system of firing.

There is one other point in Professor Nash's paper that rather interested me, and that is the allusion to the Bergius process of liquefaction. The process, of course, to most of us is still nebulous. We haven't had the opportunity of seeing it actually in operation, but it is now being used, and I understand with commercial success, by the I. G. Farben Industry, which is popularly known as the 'Aniline Dye Group' in Germany. They have installed a modified Bergius system at their works.

They have had to face particular difficulties in the question of the retorts. The retorts, or high-pressure bodies, in which the actual process of liquefaction takes place, are subject to a very large amount of wear. Shall I call it a very fast rate of deterioration? The wearing of those retorts has been held up, I believe, by critics of the Bergius system, as one of its principal evils. I believe they are overcoming it by lining the retorts with steel liners. The steel liner is replaceable. It is in the shape of a tube which can be forced, i.e., pushed

bodily, into the retort by means of a hydraulic press. My interest in this matter is not one that is able to carry us very far today in throwing light upon it, except for the fact that a big engineering concern in which I am interested was asked to make a plant upon which these tubes are prepared for insertion into the retorts. We were also asked to make a plant by which these tubes could be removed again from the retorts. So I have these actual figures that I can give you.

The length of those lining tubes is up to forty meters. The diameter is twenty-six inches. The tubes are made with one longitudinal and several circumferential seams, and after the tube is complete, it is bored inside and milled outside simultaneously to get it absolutely dead smooth and true. Then that tube is pressed by hydraulic pressure (1,800 tons) into the retort. When the tube has suffered such depreciation that it requires renewal, the press is fitted with a cutting tool which allows it to rip the tube longitudinally in half, and cut it open so that the two halves of the shell will more or less collapse and allow the withdrawal of the tube by means of the pressure press.

PROFESSOR NASH: The process Mr. Reichwald referred to was based on the fundamental researches of Bergius, but they have got their own plant which differs from Bergius' plant. I have, as a matter of fact, a letter from them regarding that.

The thought has just occurred to me that I may appear to condemn these processes generally; but I don't do so. I merely state that, so far as we are concerned in Great Britain, these synthetic oils, if I may put it so, are of very little use to us at the present moment. It is purely on the grounds of cost. In Germany we know low-temperature carbonization has been a commercial success for many years. I have seen it. Their problems are different from ours in that they use brown coal which is of very little value otherwise than for carbonizing purposes. We have very little of that coal in Great Britain.

I have just spent a good deal of time in Alberta, where tremendous quantities of coal are to be found, of all grades and conditions. I think it possible (I am speaking without having made any special study) that some of the processes

mentioned in my paper may be of use to the Province of Alberta although, as I said before, so far as we are concerned in Great Britain, they are not of very great help to us at the moment.

MR. O. N. SCOTT (Canada): I haven't had the pleasure of reading Professor Nash's paper in detail, but his reference to the tar sands of Alberta is quite interesting to us in Canada, particularly those of us who live in the west. I take it from Professor Nash's comments that under present economic conditions, or in competition with liquid petroleum as the ordinary oil is produced in the United States and other parts of the world, he considers these tar sands entirely uneconomic today as a source of oil. In that I am inclined to thoroughly agree with Professor Nash. On the other hand, however, I believe there is a possibility today of making economic use of these tar sands for paving purposes, and I rather think that is Professor Nash's view. I would like that point stressed here in case the impression should go abroad that these deposits would not be economic as a paving material.

PROFESSOR NASH: I am quite satisfied in regard to that, as I think I mentioned, because I saw several pavements which had been laid with Alberta bituminous sand. One was laid five years ago and is still standing up quite well. As a paving proposition there is nothing against the material itself being used for that purpose, provided they can get the freight reduced. At the present moment the cost of freight is so high that it would appear to be the only cause which is stopping the development, for paving purposes, of the McMurray tar sands.

DR. H. FOSTER BAIN (United States): Mr. Chairman, I would like to express my appreciation of Professor Nash's paper and emphasize, if I may, the importance of this work. I think it is very easy to fall in the habit of mind of thinking that because it is not of immediate economic importance it is something we can afford to put off. It is true that it was the war which focused attention upon the necessity of synthetic liquid fuel, but our commercial uses since the war have grown to such an extent that we have now a much greater demand

in the world than we had at the maximum period of war demand. Furthermore, the rock-oil industry is in a condition which is a very peculiar one as compared with ordinary mining industries. It is true that, generally speaking, in an oil field, or from an oil well, approximately half of the output is produced in the first year or eighteen months. As a consequence of that, it falls upon the petroleum men each year to go out and find new wells which will produce approximately half the output of the current year.

Those of you who mine gold, silver, lead, zinc, and coal, will realize what that would mean to you if each year you had to go out and find new sources equivalent to half your current output for the year. As a result of all that and the fact that so little, after all, is known of how to find oil, in spite of all that has been done, it is entirely possible that at any time within two years the world may have to have liquid fuel from synthetic sources, or a great many of our industries will have to change their methods.

When we look around just for one thing and see how intimately the automobile has been woven into our life and what it would mean to us if we couldn't run our cars or if we had to pay an extravagant price for the oil, or, worse than that, if there simply was not enough to go around at any price, we can see how important it is that we should be ready to take up this new work whenever the demand falls upon us.

As a matter of fact, a certain amount of synthetic oil is being made and a certain amount of oil is being won from oil-shales in various parts of the world. The question of whether it is economic to do it is a local question, and it may become economic to do it in Alberta long before it is economic to do it in California, for example; although it happens just at present there is one oil-shale plant running in California and delivering shale-oil into the pipe lines along with the rock oil.

MR. F. W. GRAY (Canada): Professor Nash's paper strikes me as being very opportune. The public mind, particularly the public mind in Canada, is running away with the idea that low-temperature carbonization will provide what one might call a 'cracking stock', from which, by the process of fractionization, any grade of motor spirit, lubricating oil, and other things may be obtained.

Professor Nash's paper is a very useful corrective to that over optimistic point of view. The progress of coking or heat-treatment of coal, to my mind, depends entirely on the economic needs of the country in question. The needs of Germany, for instance, for petroleum and motor spirit are very different from the needs of Great Britain.

The preference in Great Britain for a bright open-grate fire which requires a coke containing a certain amount of volatile that will ignite easily, gives another angle to this subject that we don't have in Canada, where we need a dense coke to compete with anthracite; and we are not particularly interested in petroleum because there is, at this time, an over-production of petroleum, and it is comparatively cheap. What the future may hold, nobody knows. It seems to me that I remember about fifteen years ago that Mr. David White of the United States Geological Survey, gave twenty-five years' supply only for the flowing petroleum wells of the United States. The events in the meantime have rather modified—it is hardly possible to say they have falsified—the prediction, but there certainly is no shortage of petroleum at the present time.

Professor Nash makes the following interesting statement at one point in his paper:

> "Statements have been made to the effect that it is impossible to 'crack' low-temperature tar successfully and so obtain an increased yield of motor spirit, but such views should be accepted with caution, as sufficient experimental evidence has not yet been forthcoming to enable a definite opinion to be expressed. Tars from different coals and from different methods of retorting varying to such a considerable extent, and our knowledge of this material being so slight, it would be dangerous to dogmatize on any such point".

Might I ask Professor Nash what he thinks of the claim of the Sensible Heat Distillation people, for example, that the product which comes from coal at certain temperatures is virtually the same in constitution no matter whether the product treated is a fat bituminous coal or lignite or a coal of another variety. It seems to be an extraordinary claim that is being made, that at a certain temperature the oil or

the distillate obtained from coal is of the same chemical characteristics and upon distillation will yield a certain regular grade of product, depending on the product desired and the fractionation point obtained. That statement, to my mind, seems at least peculiar.

I would like to remark that in Canada our search for a product in substitution for anthracite has only led so far to the use of coke made in the by-product oven. The by-product oven today recovers tar of a commercial grade. Motor spirit, benzol, which is very satisfactory, can be used alone or can be used in combination with gasoline and is so being used by the Imperial Oil Company very largely in Nova Scotia today and is used the same way in the Southern United States, Alabama and such places.

For years I ran my motor car on crude benzol. It is a little dirty, but it is all right. Sulphate of ammonia is produced and that is a substance for which there is considerable sale, both in Canada and in the West Indies. The product of low-temperature carbonization in its present state is a tar which is not saleable, a tar which the tar distillers will not ask for. It doesn't contain the elements they require. The coke is a semi-solid mass that is of no particular value until it has been briquetted. The yield of fertilizers from the low-temperature carbonization process is very small. I think the economic viewpoint is that coal should be carbonized to yield the substances most desired. One cannot force use of a process where it is not required. The time has not yet arrived in North America when the coal producer can afford to go into competition with the oil refiners.

I take it that Professor Nash's paper represents very largely the viewpoint of the oil man. Suppose a colliery could today put up a low-temperature carbonization plant and obtain a 'cracking stock'; it is hardly to be expected it is going to go into competition with the oil-refining companies which have their organizations and their technical men, their sales organizations, because that is practically what it would mean. So far as I can see at the present time, low-temperature carbonization is not a matter of any great interest to eastern Canada. It may be of interest to the west eventually, but not at the present moment.

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